JET PROPULSION

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AMERICAN ROCKET SOCIETY

Rocketry . . . . . Jet Propulsion Sciences . . . . . Astronautics

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JANUARY 24 — ARS-IAS JOINT SESSION (IAS ANNUAL MEETING) — SEE PAGE 713

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JET PROPULSION, the Journal of the American Rocket Society, is devoted to the advancement of the field of jet propulsion through the publication of original papers disclosing new knowledge and new developments. The term "jet propulsion" as used herein is understood to embrace all engines that develop thrust by rearward discharge of a jet through a nozzle or duct; and thus it includes systems utilizing atmospheric air and underwater systems, as well as rocket engines. JET PROPULSION is open to contributions, either fundamental or applied, dealing with specialized aspects of jet and rocket propulsion, such as fuels and propellants, combustion, heat transfer, high temperature materials, mechanical design analyses, flight mechanics of jet-propelled vehicles, astronautics, and so forth. JET PROPULSION endeavors, also, to keep its subscribers informed of the affairs of the Society and of outstanding events in the rocket and jet propulsion field.

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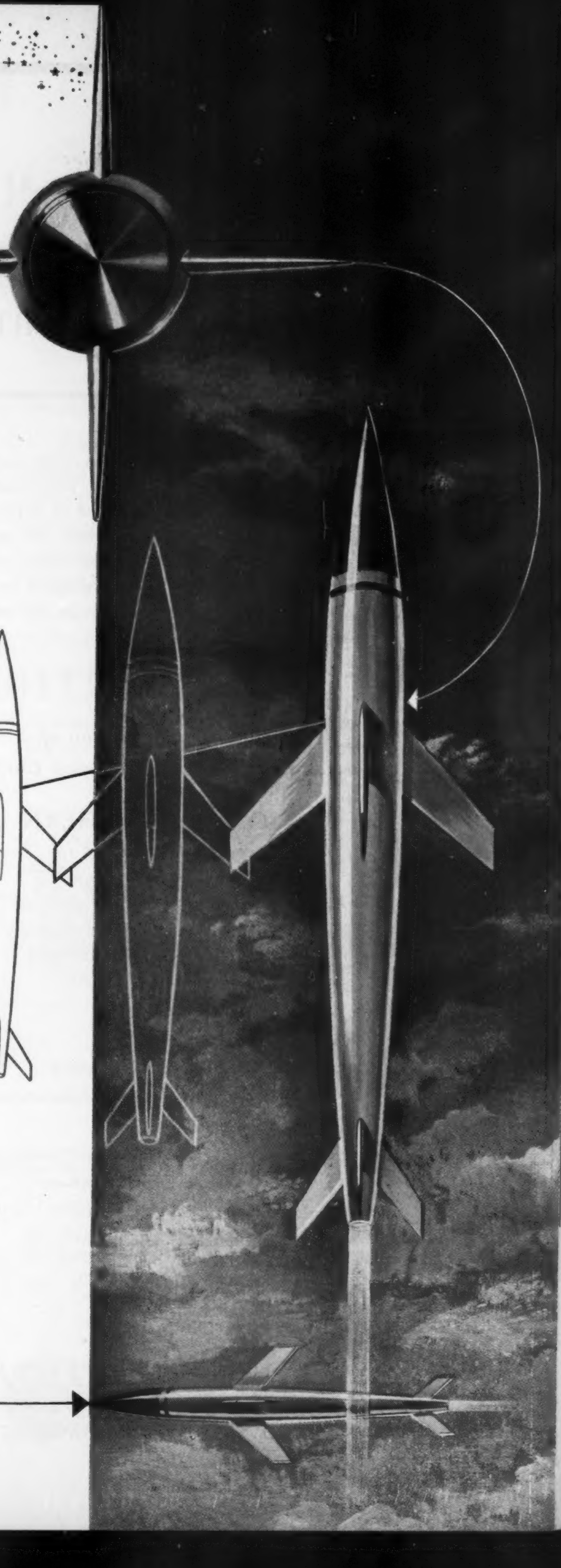
ISSILES IN ERSPECTIVE



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G.E. at Work
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Project Vanguard underway as G.E. teams up with Martin Baltimore to get Satellite vehicle off earth into upper atmosphere

Even as you read this, General Electric has begun work on the powerful rocket engine that will launch the world's first earth satellite.

PROJECT VANGUARD, under U.S. Navy management, will be the initial step toward the exploration of space. The satellite will be carried up in a three-stage rocket built by Martin Baltimore. It will then spin around the earth, at an altitude of some 200 miles, transmitting a description of conditions in outer space. This radio-wave description may include information on the nature of the sun, solar radiation, cosmic noise, and magnetic noises and their cause . . . enabling scientists to better understand the laws of the universe.

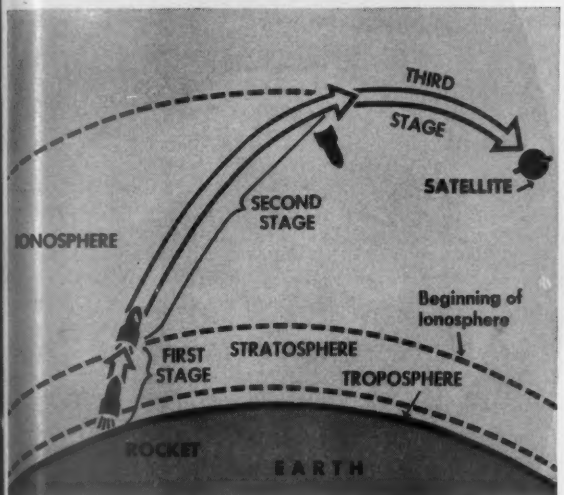
G-E DESIGN DATA ON POWERFUL ENGINE for VANGUARD's first stage cannot be revealed at this time. However, it can be said that static firing tests of similar-type G-E engines have been highly successful.

LAUNCHING OF THE SATELLITE will mark still another milestone in rocket engine progress at General Electric. Since 1945, when G-E scientists and engineers followed advancing Allied armies to study captured German V-2 rockets, the company has been constantly developing better, more powerful rocket engines. It was under G-E supervision, for example, that the existing altitude record of 250 miles for a two-stage rocket was established.

GENERAL ELECTRIC'S CONTRIBUTION to PROJECT VANGUARD climaxes the company's first decade of rocket engine development. G-E experience and know-how will continue to pay off in more powerful, more reliable rocket engines for American aviation.

VIKING ROCKET, built by Martin Baltimore, roars from launching pad at White Sands, New Mexico. Martin's new VANGUARD airframe may be similar in appearance to this U.S. Navy high-altitude research vehicle.

on New Rocket Powerplant
First Earth Satellite Project



G-E ENGINE WILL LIFT SATELLITE many miles upward, then drop off. Second engine will take over, push satellite to 2-300-mile height where third powerplant will blast satellite into 18,000-mph, egg-shaped orbit around the earth.

COMBUSTION RESEARCH is a vital phase of G.E.'s investigations in rocket engine development. Modern labs, coupled with top rocket engine design engineers, are now yielding rapid forward strides in powerplant development.

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HALF-SIZE MODEL OF PREVIOUS G-E ENGINE is examined by A. P. Adamson and D. Cochran of G.E.'s Aircraft Gas Turbine Development Department. VANGUARD powerplant will be similar, but will use new fuels to assure high performance.

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Editor-in-Chief
MARTIN SUMMERFIELD

Photography from the Viking 11 Rocket

LEOPOLD WINKLER[1]

Naval Research Laboratory, Washington, D. C.

On May 24, 1954, Viking 11 was launched at White Sands Proving Ground, New Mexico. The research equipment in the rocket included an aircraft camera, which took thirty-nine pictures at altitudes varying from sixty-five miles on the ascent, through the peak of 158.4 miles, to [illegible] miles on the descending portion of the trajectory. Great care in focusing the camera lens produced photographs with excellent definition. The ten photos which are presented show the area near White Sands and interesting features of the earth's surface, cloud formations, and the atmospheric layer at the horizon.

Most of the material presented in this paper is taken from the Naval Research Laboratory Report no. 4489, "Photography from the Viking 11 Rocket at Altitudes Ranging up to 158 miles," by R. C. Baumann and L. Winkler.

Introduction

SINCE the Naval Research Laboratory began its rocket research program about nine years ago, cameras have been installed in many of the rockets. Three types of cameras have been used—16-mm motion picture cameras at 5 frames per sec for determining rocket aspect; the same motion picture cameras at 16 frames per sec to record rocket spin, nose separation, and other functions; and, finally, the K-25 aircraft camera with its 4 × 5-in. picture, is used to record meteorological information.

Of these types, the aircraft camera has the best definition by far, and the pictures obtained with this camera are of great interest because they show such vast expanses of the earth's terrain with remarkable clarity.

The Naval Research Laboratory obtained its first reasonably good high-altitude photographs on a V-2 rocket flight in March 1947 (1).[2] Little improvement in definition or altitude was obtained until the flight of Viking 11, on May 24, 1954. This rocket reached an altitude of 158.4 miles, the greatest height from which photographs of the earth have yet been taken.

The Camera

The pictures were taken with a K-25 aircraft camera (Fig. 1), the same type used previously. The greatest problem in high-altitude photography was recovery of the film in good condition. On earlier flights sheet metal housings were built to enclose the camera. Recovery was poor, the case frequently opened on impact, and the film was exposed. This difficulty was first overcome by Mr. Clyde Holliday of the Applied Physics Laboratory. He armored the K-25 so successfully that it was possible to fly the same camera time and time again (2). In the Viking rocket, weight is more important than it was in the older V-2. With this in mind, the Naval Research Laboratory modified the K-25 by adding only a steel cassette into which the film is wound. The cassette, which weighs $3^1/_2$ lb, has proved to be excellent protection, and recovery of the film in good condition is no longer the problem it used to be.

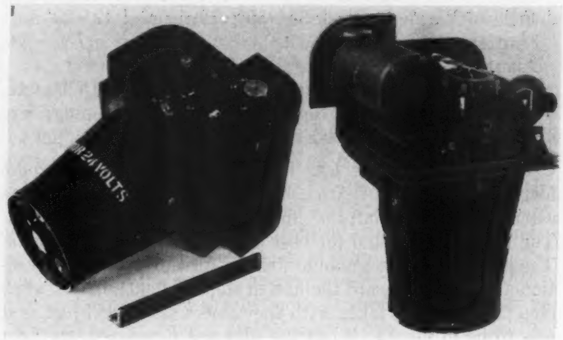


Fig. 1 K-25 camera

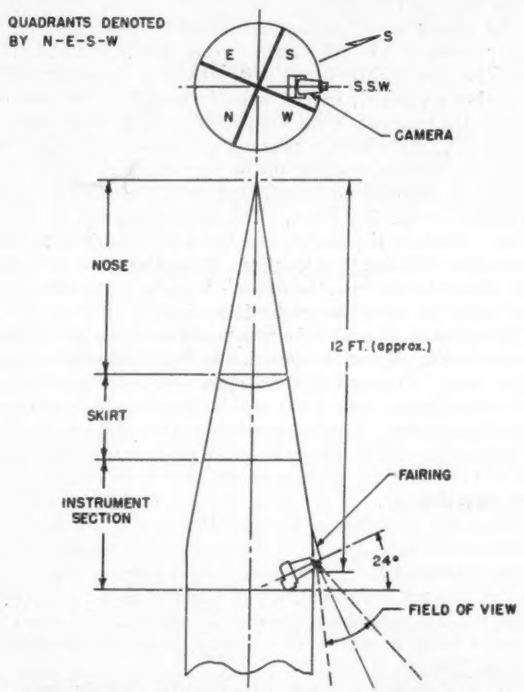


Fig. 2 Instrumentation section of rocket showing orientation of camera

Presented at the 25th Anniversary Spring Meeting of the AMERICAN ROCKET SOCIETY, Baltimore, Md., April 21, 1955.
[1] Head of the Structures Section, Rocket Development Branch.
[2] Numbers in parentheses indicate references at end of paper.

The camera was installed in the instrument section of the rocket, approximately twelve feet from the tip, as shown in Fig. 2. The camera was fitted with a right-angle prism so that the camera body would not protrude beyond the rocket skin, even though the earth, almost directly below the rocket, was in the field of view as the rocket ascended. The axis of the camera was inclined twenty-four degrees upward from the horizontal so that the rocket body would not appear in the pictures. The camera was installed in the rocket so that it pointed south-southwest at take-off.

Camera details are as follows:

Camera—Modified K-25 aircraft (24 volts d-c, 3.2 amp), weight 15 lb
Prism—Right-angle Navy stock No. E18P24669490
Filter—Infrared (between lens and prism)
Lens—Ilex Paragon Anastigmat f4.5, 163 mm focal length
Field of View—Vertical, 34°-30′; Horizontal 42°-20′
Shutter—Set at $^1/_{500}$ sec
Aperture—Set at f8
Film—Kodak Aero Safety Film Type 1A Army Class K, Hi Speed Infrared, topographic base for mapping; exposure index 100 with red filter, $5^1/_4$ in. × 20 ft.

The position of the lens in the camera for the sharpest focus was determined from test photos. The camera was assembled with the infrared filter and put on an optical bench. The lens was adjusted for best focus on a ground-glass plate. The lens then was set about 0.006 in. forward from that position and moved toward the film in steps of 0.002 in. At each step pictures were taken with the camera assembled just as it was to be in flight. When the film was developed, the best lens setting was found. This setting was then corrected for operation in a vacuum; the correction moved the lens 0.004 in. toward the film.

The impact of the section containing the camera was unusually gentle. The only damage to the camera was a chipped prism and one slightly bent shaft. It was in operating condition when recovered; in fact, since the bent shaft has been replaced, the camera is considered suitable for another flight.

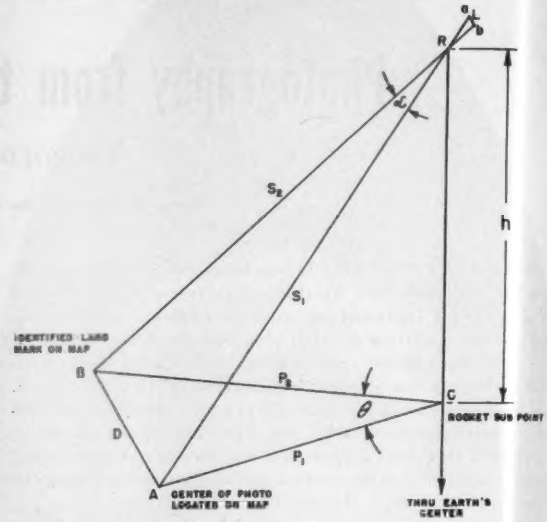
The K-25 is electrically operated and was to take a picture every six seconds, starting on the way up, at about fifty-five miles (124 seconds) and continuing for 312 seconds to about 113 miles on the way down. The camera received its pulses from a timer in the rocket, and the time of each pulse was accurately recorded by telemetry. From this time record and the data obtained from the rocket's trajectory, the altitude of the rocket at any pulse can be determined.

Unfortunately, a mistake was made in wiring the camera in the rocket, so that its operation in flight differed from preflight tests. During flight, the camera did not take a picture on every pulse; only thirty-nine pictures were taken from sixty-five pulses. In order to determine the altitude at which a picture was taken, the pulse which produced it would have to be known, or the altitude would have to be calculated by photogrammetry.

Since the camera was operable after recovery, rolls of film were run through it to see if there were some regular pattern to its malfunctioning. In six such runs, little correlation was found between individual runs. This test showed, however, that the first pulse never operated the camera, and, when the camera failed to operate on one pulse, it always operated on the next pulse.

It was necessary, then, to calculate altitude from the photographs, and for this purpose a large number of contour maps of the area were procured. The altitude obtained in this manner is not quite as accurate as that which is available when the photograph and the pulse which produced it can be correlated.

The reasons for inaccuracy in altitude calculated by photogrammetry are: distortion caused by the camera lens; distortion caused by the enlarger lens (all work was done on 6× enlargements); distortion due to uneven shrinkage in the paper; difficulty in precisely locating points on the picture and on the map; and difficulty in precisely measuring the distance between points. Hence each picture was identified with the nearest pulse, and the altitude of the rocket at the time of the pulse is the altitude assigned to the picture.



P_1 & P_2 ARE PERPENDICULAR TO $\overline{RC}$

$$\frac{\text{ab LENGTH ON PHOTO}}{\text{MAGNIFICATION}} = L \quad \text{(LENGTH ON NEGATIVE)}$$

$$\operatorname{Tan} \alpha = \frac{L}{f} \qquad f = \text{FOCAL LENGTH OF LENS}$$

$$h^2 + P_1^2 = S_1^2 \qquad h^2 + P_2^2 = S_2^2$$

$$D^2 = S_1^2 + S_2^2 - 2S_1 S_2 \operatorname{Cos} \alpha$$

$$D^2 = h^2 + P_1^2 + h^2 + P_2^2 - 2\sqrt{(h^2+P_1^2)(h^2+P_2^2)} \operatorname{Cos} \alpha$$

$$(1-\operatorname{Cos} \alpha^2) h^4 + \left[(P_1^2+P_2^2-D^2) - (P_1^2+P_2^2) \operatorname{Cos} \alpha^2 \right] h^2 + \left[\frac{(P_1^2+P_2^2-D^2)^2}{4} - P_1^2 P_2^2 \operatorname{Cos} \alpha^2 \right] = 0$$

Fig. 3 Method for calculating altitude

The method which was used for calculating altitude is shown in Fig. 3. In this method, the rocket subpoint must be known. The subpoint was established for each picture from a projection of the trajectory on the earth's surface. Because of the Coriolis effect, the projection is not a straight line between the points of take-off and impact, and the deviation from a straight line was calculated to be approximately 3.4 miles toward the east at the peak altitude.

In addition to the subpoint, the center of the picture and another well-defined point must be identified on the map, so that the distances D, P_1, and P_2 can be measured.

The distortions which were mentioned previously are least at the center of the picture, so that the most accurate results are obtained if distances near the center are used in the calculations. It is preferable to choose points so that P_1 and P_2 are nearly the same and the angle θ is small, i.e., less than one fourth of the angular field of view.

A more exact method for determining altitude, which was based on the spherical shape of the earth, was tried at first. The difference in altitude by this method was less than the variation in altitude from different base lines, which indicates that greater errors are introduced in obtaining measurements than in the method of calculating.

The purpose of calculating the altitude from the photo was to identify the picture to the correct pulse, but the calculations were not necessary after the first few photos. All that was needed then was to measure the distance between two points as they appeared on successive pictures. The difference in length quickly indicated when a pulse had been skipped.

As the rocket approached peak, the differences became smaller and smaller, until no reasonable difference could be measured after picture No. 15 (154.2 miles). The results of

the work up to this picture indicated that the camera followed a regular pattern of operation, and for the remaining pictures the same pattern was assumed. To check this assumption, the altitude of picture No. 38 (48.1 miles) was calculated in the same way as No. 1 through No. 9. As before, the altitudes were so nearly alike that there is no doubt that picture No. 38 was taken on pulse No. 63, the same pulse that extrapolation of the pattern indicates. Table 1 shows the correlation between the pulses and the pictures.

Table 1

Pulse	Seconds after take-off	Altitude (miles above sea level) From trajectory	From photo	Picture no.
1	123.6	58.5		
2	129.7	65.0	64.0	1
3	135.8	71.8	71.5	2
4	141.9	77.4		
5	148.0	83.2	83.6	3
6	154.1	88.9		
7	160.2	94.3	94.3	4
8	166.4	99.5	99.3	5
9	172.5	104.5		
10	178.6	109.2	108.6	6
11	184.7	113.7		
12	190.8	118.1	118.2	7
13	197.0	122.2	121.9	8
14	203.1	126.0		
15	209.2	129.7	129.5	9
16	215.4	133.1	↑	
17	221.5	136.3	Matched by dif-	10
18	227.6	139.3	ference in	11
19	233.7	142.1	length be-	
20	239.9	144.7	tween two	12
21	246.0	147.0	points on suc-	
22	252.1	149.1	cessive photos	13
23	258.3	151.1		14
24	264.4	152.7		
25	270.6	154.2		15
26	272.7	155.5	↓	
27	282.8	156.5	↑	16
28	289.0	157.3		17
29	295.1	157.9		
30	301.3	158.3	Matched by ex-	18
31	307.4	158.4	trapolation of	
32	313.6	158.4	previous pat-	19
33	319.7	158.1	tern	20
34	325.9	157.6		
35	332.0	156.9		21
36	338.2	156.0		
37	344.3	154.8		22
38	350.4	153.5		23(Blank)
39	356.5	151.9		
40	362.6	150.1		24(Blank)
41	368.7	148.1		
42	374.8	145.9		25
43	380.9	143.4		26
44	387.0	140.8		
45	393.1	137.9		27
46	399.2	134.8		
47	405.3	131.4		28(Blank)
48	411.4	127.9		29(Blank)
49	417.5	124.1		
50	423.6	120.2		30
51	429.7	116.0		
52	435.8	111.6		31
53	441.9	107.9		32(Blank)
54	448.0	102.1		
55	454.1	97.0		33
56	460.2	91.7		
57	466.3	86.1		34
58	472.4	80.4		35
59	478.5	74.4		
60	484.6	68.3		36(Blank)
61	490.7	61.9		
62	496.8	55.2		37
63	502.9	48.1	44.9	38
64	509.0	40.8		
65	515.1	33.3	↓	39

Description of the Pictures

The rocket fired at 10:00 a.m. rose vertically from its launching platform and shortly after was inclined to the north. Its fuel burned out at 104.7 sec after take-off at an altitude of 37 miles. From the time it was launched until slightly past peak, a carefully designed stabilization system reduced the pitch and roll to a few degrees. Then, at 331.8 sec, steam control jets in the body of the rocket were turned on. They caused the rocket to rotate slowly so that, 19 sec later, when the nose was separated from the afterbody, the nose was pointing toward the earth. After separation, the motion of the afterbody, which carried the camera, was uncontrolled and its gyration was unpredictable.

The photographs which follow are representative of the group. All of the photos are not shown because many are nearly alike. For example, during the stabilized portion of the flight, twenty pictures were taken. All of these showed the same general area centered about El Paso, with very little change between successive photos. Consequently, the seventeen pictures between the first photo and the one taken at peak are omitted. After the rocket was made to tumble, there was no control over the orientation of the camera, and this resulted in the interesting group taken on the way down. During this portion of the flight, six pictures were taken while the camera was pointed at the sky. These photos are uniformly black and are listed in the table as blanks.

A composite picture was made from the two photos shown in Figs. 6 and 9. The left side of the composite (Fig. 14) was photographed at an altitude of 154.8 miles, the right side was photographed a half minute later and 16.9 miles lower. It was necessary to make two enlargements with different scales of Fig. 9 (right side) so that the outstanding features could be matched very closely along the adjoining edges.

Large scale maps were very useful in identifying nearly all the landmarks seen in the photographs. Transparent overlays on which most of the important landmarks are shown would be very helpful so that the areas can be recognized more easily.

Acknowledgments

The excellent photographs which were obtained from the flight of Viking 11 are the results of painstaking care by many people. Other agencies assisted by furnishing information and material which was needed.

Among those who assisted are:

1 The Naval Research Laboratory—Mr. Otto Berg recommended all camera settings and the method of focusing the lens.

2 New Mexico College of Agriculture and Mechanic Arts—Mr. Stewart Bean focused the camera, installed it in the rocket, and developed the recovered film.

3 The National Bureau of Standards—Mr. W. Darling determined the focal length of the camera lens.

4 The U. S. Geological Survey furnished topographic maps necessary in altitude calculations.

5 The Army Map Service—Dr. C. E. Dofflemyer provided many helpful ideas and furnished topographic maps used in altitude calculations.

References

1 "Photography from the V-2 Rocket at Altitudes Ranging up to 160 Kilometers," by T. A. Bergstralh, NRL Report no. R-3083, April, 1947.

2 "Preliminary Report on High Altitude Photography," by Clyde T. Holliday, *Photographic Engineering*, January 1950.

TOP, OPPOSITE PAGE

Fig. 4 Picture No. 1 was taken at an altitude of 65 miles

The Rio Grande and the cultivated area at its borders runs diagonally across the picture. The railroads to El Paso are easily identified, but the highways are more difficult to see. The two airfields at El Paso show up clearly with the runways of Biggs more easily seen than those of Municipal Airport. The city of Las Cruces is obscured by a cloud. The picture covers an area as shown in the following sketch.

	66.5 m	
47.9 m		54.7 m
	48.8 m	

BOTTOM, OPPOSITE PAGE

Fig. 5 Picture No. 19, taken at an altitude of 158.4 miles, is the highest known picture of the earth at this writing

The direction in which the camera was pointed is the same on picture No. 1 and No. 19, and the pictures between indicated the rocket rolled very little. Most of the features which can be seen on the first picture are still discernible. The Mexican railroads running south from Juarez could not be distinguished on any of the photos. This is probably caused by the light-colored rock ballast which the Mexican railways use. The picture covers an area approximately as shown in the following sketch.

	150 m	
120 m		140 m
	100 m	

TOP, RIGHT

Fig. 6 Picture No. 22, taken at an altitude of 154.8 miles, shows the horizon and clouds to the southeast

At this altitude, the horizon is 1120 miles away. The Gulf of Mexico, about 650 miles away, would be plainly visible had there been no clouds. The body of the rocket now has a tumbling motion, a maneuver initiated about 12 seconds earlier.

CENTER, RIGHT

Fig. 7 Picture No. 25, from 14.59 miles, shows the area nearly northwest of the rocket

Roosevelt Lake, which shows so clearly in the picture, is about 325 miles from the rocket. The Colorado River is barely visible in the upper left-hand corner. There are no large cities in this area. Phoenix, southwest from Lake Roosevelt, is just beyond the field of view, but it is included on a later picture, No. 34.

BOTTOM, RIGHT

Fig. 8 Picture No. 26, taken at 143.4 miles is the best picture of the area around the launching site

The approximate area covered by this picture is shown in the following sketch.

	95 m	
75 m		100 m
	100 m	

Fig. 9 Picture No. 27, from 137.9 miles, shows the rugged country to the south southeast

The horizon is 1050 miles from the rocket. Detailed maps of this area were not available, so that identification of the landmarks was difficult. The Big Bend portion of the Rio Grande and its confluence with the Rio Concho near Presidio is indicated.

Fig. 12 Picture No. 35, from 80.4 miles, was included because it shows the foothills of the Sacramento mountains in such great detail

The rectangular plats of Dell City, Texas, and the salt basin to the east are clearly visible.

Fig. 10 Picture No. 30, from 120.2 miles, shows a large area of Mexico to the south. A few of the known landmarks are identified

Fig. 13 Area (approximately 600,000 sq miles) included in composite photograph of earth taken from Viking 11

Fig. 11 Picture No. 34, from 86.1 miles, shows the area to the west. Roosevelt Lake, which first appeared on picture No. 25 (see Fig. 7) is clearly seen

The horizon is 830 miles away and the distance across the picture, at the horizon, is about 610 miles. Notice the nose cone which was separated 116 seconds earlier. It is about 640 feet away and its orientation indicates it has a large angle of attack. The identifying painting on the skirt can be seen.

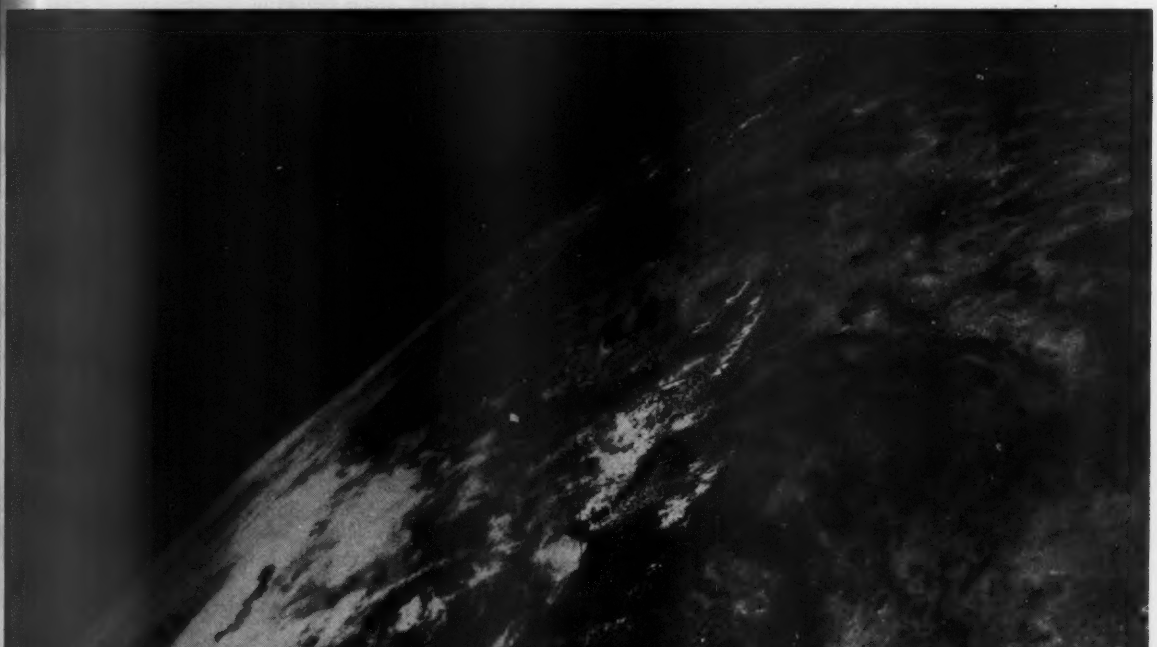


Fig. 14 A composite picture of two photographs showing about degrees 60 of the horizon to the southeast

Thrust Characteristics of Underexpanded Nozzles[1]

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The thrust characteristics of underexpanded nozzles are investigated both analytically and experimentally. Nozzle losses are expressed in terms of velocity coefficients and this theory is found to agree with the experimental results. Two basic nozzles were tested, each having a $^1/_2$-in. throat diam and 15 deg exit semiangle cone. One nozzle had a smooth surface of 20 microin. while the other had a rough surface of 300 microin. Area ratios from 6 to 1 were tested by machining the nozzle exit plane normal to the nozzle axis. High-pressure, low-temperature air was used as the working medium with a nozzle inlet test pressure of 33 atmospheres. The theoretical development predicts, and the experimental results verify, that the maximum nozzle thrust is obtained from an area ratio less than that required for complete expansion. It is further shown that thrust equal to that for complete expansion may be obtained from a nozzle having an area ratio of little more than half of that required for complete expansion.

Nomenclature

A_c = nozzle throat area
A^* = nozzle exit area
C_T = thrust coefficient
F = nozzle thrust
g_c = gravitational conversion factor
h_e = nozzle exit enthalpy
h_e' = isentropic exit enthalpy
h_{t1} = nozzle inlet stagnation enthalpy
h^* = nozzle throat enthalpy
$(h^*)'$ = isentropic throat enthalpy
$\dot{m}$ = nozzle mass flow rate
$\dot{m}'$ = isentropic mass flow rate
P_a = ambient pressure
P_e = nozzle exit pressure
P_{t1} = nozzle inlet stagnation pressure
P^* = nozzle throat pressure
$(P^*)'$ = isentropic nozzle throat pressure
$\bar{R}$ = universal gas constant
N = molecular weight
T_e = nozzle exit temperature
T_{t1} = nozzle inlet stagnation temperature
T^* = nozzle throat temperature
V^* = nozzle throat velocity (sonic)
$(V^*)'$ = isentropic velocity at nozzle throat pressure
V_e = nozzle exit velocity
V_e' = isentropic exit velocity
α = $\frac{1}{2}(\cos\beta + 1)$ = nozzle divergence correction factor
β = nozzle exit cone semiangle
γ = specific heat ratio
ϕ = nozzle exit velocity coefficient
ϕ^* = nozzle throat velocity coefficient
η_m = nozzle mass flow efficiency
λ = parameter defined by Equation [13]

Introduction

IN THE past it has been assumed that a rocket nozzle operating with complete expansion (nozzle exit-plane pressure equal to ambient pressure) will produce the greatest thrust for a given nozzle inlet condition and propellant. It has been proposed in Refs. (1) and (2)[3] that it is actually possible to obtain a slight increase in thrust from an underexpanded nozzle (nozzle exit-plane pressure greater than ambient pressure) as compared to the completely expanded nozzle with the same inlet conditions. This phenomenon is explained briefly as follows:

For underexpanded nozzles the thrust developed consists of two parts—the momentum thrust, and the pressure thrust. In the case of isentropic flow, the thrust for a given nozzle inlet condition will be maximum when the pressure thrust is zero—that is, when complete expansion to ambient pressure takes place within the nozzle. In the actual, nonisentropic case, however, some degree of underexpansion will reduce the energy loss due to friction within the nozzle and the pressure thrust may more than compensate for the reduction in momentum thrust caused by the underexpansion.

The analyses presented in (1) and (2) are based on the one-dimensional flow of an ideal gas and lack experimental verification. In order to investigate experimentally the thrust characteristics of underexpanded nozzles, a test program was undertaken using high-pressure low-temperature air as a working fluid. Tests were made on small conical-exit de Laval nozzles using the blow-down nozzle test facility described in (6). Varying amounts of underexpansion were obtained by progressively machining the nozzle exit plane normal to the nozzle axis. The results of this program are presented here along with the theoretical basis for the tests.

Theoretical Analysis

Simplifying Assumptions

The following assumptions apply to the analysis to be presented:

1. The flow is steady, adiabatic, and one-dimensional except that the thrust may be corrected for three-dimensional exit effects by a divergence correction factor, α, as given in (3).
2. The boundary layer is neglected except as a source of friction.
3. The working fluid is an ideal gas having constant specific heat.

These assumptions are commonly made for rocket nozzle flow analyses (4, 5) and will be used here in order to obtain relatively simple mathematical statements for the nozzle flow. The assumption of an ideal gas with constant specific heat is not necessary for a one-dimensional flow, since an analytical solution can be made using a complex equation of state such as the Beattie-Bridgman equation; or numerical solutions can be made using tables of thermodynamic properties of the working fluid. However, such analyses obscure the relation between the important parameters and lose the value of mathematical simplicity.

Thrust Equation

The thrust of a rocket nozzle is given by the following well-

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[3] Numbers in parentheses indicate References at end of paper.

known relation, composed of a momentum term and a pressure term

$$F = \alpha \frac{\dot{m}}{g_c} V_e + A_e(P_e - P_a) \quad [1]$$

Complete expansion in a nozzle flow occurs when the nozzle exit pressure is equal to the ambient pressure. As shown in Equation [1], when this occurs the pressure term becomes zero and the entire thrust is due to the momentum change. In an underexpanded nozzle, the nozzle exit pressure is greater than the ambient pressure and the pressure term makes a positive contribution to the nozzle thrust, as shown by Equation [1]. For isentropic flow, it can be shown (1) that the thrust is a maximum for a given nozzle inlet and ambient pressure when complete expansion occurs. Actual nozzle flow is not isentropic, however, but is accompanied by an entropy increase caused by friction. The effect of this entropy increase on nozzle thrust will be analyzed in the following sections.

Nonisentropic Flow

The effects of nonisentropic nozzle flow can be shown in an enthalpy-entropy diagram, such as Fig. 1. As shown in Fig. 1, since the flow is considered to be adiabatic, the stagnation enthalpy is constant at all points in the flow. For an ideal gas this requires the stagnation temperature to be constant at all points in the flow. The stagnation pressure decreases from inlet to exit because of the entropy increase. Neglecting three-dimensional effects, the throat velocity will be sonic in the actual case as well as in the isentropic case.

A measure of the entropy increase in nozzle flow is the velocity coefficient, ϕ, which is defined as the ratio of the actual velocity at a point in the flow to the velocity which

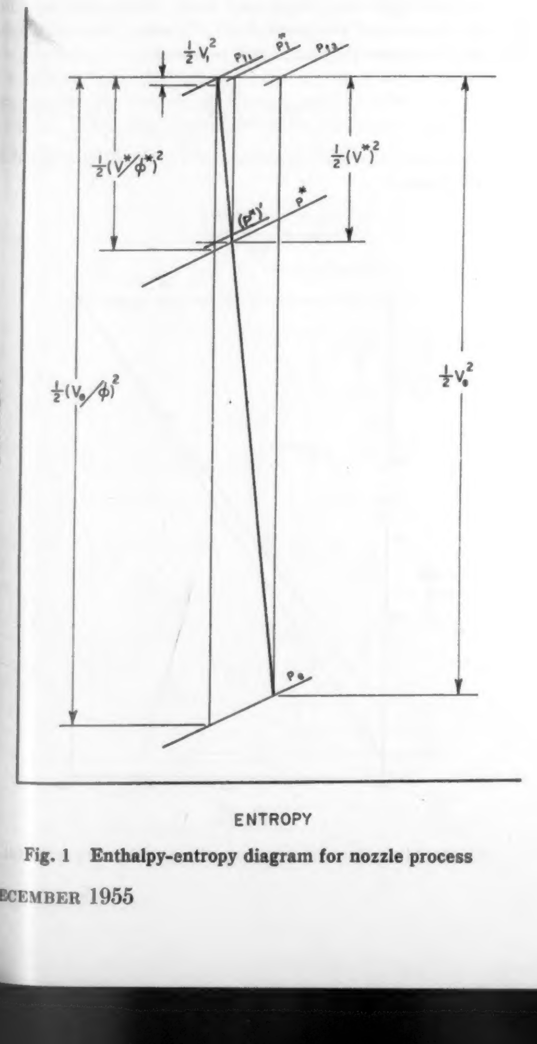


Fig. 1 Enthalpy-entropy diagram for nozzle process

would result from isentropic flow to the same pressure as that of the point in the actual flow. Thus, by definition, the exit coefficient is

$$\phi = \frac{V_e}{V_e'} \quad [2]$$

Using the same definition, the velocity coefficient at the throat is

$$\phi^* = \frac{V^*}{(V^*)'} \quad [3]$$

The relation of these velocity coefficients to the enthalpy changes for actual and isentropic flow is shown in Fig. 1 in terms of the actual velocities. In terms of enthalpy these coefficients are

$$\phi = \sqrt{\frac{h_{t1} - h_e}{h_{t1} - h_e'}} \quad [4]$$

$$\phi^* = \sqrt{\frac{h_{t1} - h^*}{h_{t1} - (h^*)'}} \quad [5]$$

For an ideal gas with constant specific heat, Equation [4] becomes

$$\phi = \sqrt{\frac{1 - T_e/T_{t1}}{1 - (P_e/P_{t1})^{(\gamma-1)/\gamma}}} \quad [6]$$

Making use of the temperature relation for sonic velocity and the fact that the stagnation temperature is constant

$$\frac{T^*}{T_{t1}} = \frac{2}{\gamma + 1} \quad [7]$$

gives the throat velocity coefficient as

$$\phi^* = \sqrt{\frac{(\gamma - 1)/(\gamma + 1)}{1 - (P^*/P_{t1})^{(\gamma-1)/\gamma}}} \quad [8]$$

The throat velocity, which is sonic, for an ideal gas with constant specific heat is

$$V^* = \sqrt{\frac{2\gamma g_c \bar{R} T_{t1}}{(\gamma + 1)N}} \quad [9]$$

The exit velocity, from Equation [4], for an ideal gas with constant specific heat is

$$V_e = \sqrt{\frac{2\gamma g_c \bar{R} T_{t1}}{(\gamma - 1)N}\left[1 - (P_e/P_{t1})^{(\gamma-1)/\gamma}\right]} \quad [10]$$

Aera Ratio

It is now possible to determine the nozzle area ratio for nonisentropic flow in terms of the velocity coefficients, specific heat ratio, and pressure ratio.

For a one-dimensional flow of an ideal gas the continuity equation is

$$\dot{m} = \frac{AVPN}{\bar{R}T} \quad [11]$$

Applying this equation at the throat and exit gives

$$\frac{A_e}{A^*} = \frac{V^* P^* T_e}{V_e P_e T^*} \quad [12]$$

The velocity coefficients may now be introduced into this relation. Let

$$\lambda = 1 - (P_e/P_{t1})^{(\gamma-1)/\gamma} \quad [13]$$

Substituting for V^* from Equation [9], V_e from Equation [10], P^* from Equation [8], T_e from Equation [6], and T^* from Equation [7] results in

$$\frac{A_e}{A^*} = \frac{\sqrt{(\gamma - 1)/(\gamma + 1)}\, 1 - \phi^2\lambda}{2(P_e/P_{t1})\phi\sqrt{\lambda}}\left[1 - \frac{\gamma - 1}{(\phi^*)^2(\gamma + 1)}\right]^{\gamma/(\gamma-1)} \quad \text{.....[14]}$$

Thrust Coefficient

The thrust coefficient for a nozzle is defined as the net thrust of the nozzle divided by the product of the nozzle inlet stagnation pressure and nozzle throat area. That is

$$C_T = \frac{F}{A^* P_{t1}} \quad \text{.....[15]}$$

The effect of nonisentropic flow on the nozzle thrust can now be shown in terms of the thrust coefficient for given values of throat area and nozzle inlet stagnation pressure.

Substituting Equation [11] into Equation [1] and making use of Equation [15] give

$$C_T = \frac{\alpha A_e P_e V_e^2 N}{A^* g_c \bar{R} T_e P_{t1}} + \frac{A_e}{A^*}\left(\frac{P_e}{P_{t1}} - \frac{P_a}{P_{t1}}\right) \quad \text{.....[16]}$$

Substituting for V_e from Equation [10] and T_e from Equation [6] gives

$$C_T = \frac{A_e P_e}{A^* P_{t1}}\left[\frac{2\lambda\alpha\phi^2\gamma/(\gamma - 1)}{1 - \phi^2\lambda} + 1\right] - \frac{A_e P_a}{A^* P_{t1}} \quad \text{...[17]}$$

From Equations [14] and [17] the thrust coefficient can be plotted as a function of area ratio for given operating pressure limits and specific heat ratio with the pressure ratio and velocity coefficients as parameters.

In Fig. 1 it has been assumed that the entropy increase from the inlet to any point is essentially proportional to the square of the velocity at the point. This is equivalent to assuming the velocity coefficient to be uniform at all points along the flow axis, and in particular, that the throat velocity coefficient, ϕ^*, is equal to the exit velocity coefficient, ϕ. A uniform velocity coefficient between the throat and the nozzle exit for conical nozzles has been indicated in (8), based on experimental evidence, and this assumption is further justified by the experimental data of this report.

Fig. 2 is a plot of thrust coefficient as a function of area ratio for a 15-deg exit semiangle nozzle with the throat and exit velocity coefficients taken as equal and shown as parameters. An over-all pressure ratio of 0.012 is given and a specific heat ratio of 1.25, which is typical of the specific heat ratio for rocket propellants, is used. As shown in Fig. 2, the area ratio for maximum thrust decreases with decreasing velocity coefficient. It is also shown that the curves of thrust coefficient vs. velocity ratio are relatively flat in the region of the maximum thrust coefficient and that the thrust does not begin to drop sharply until an area ratio of approximately half of that necessary for complete expansion is reached.

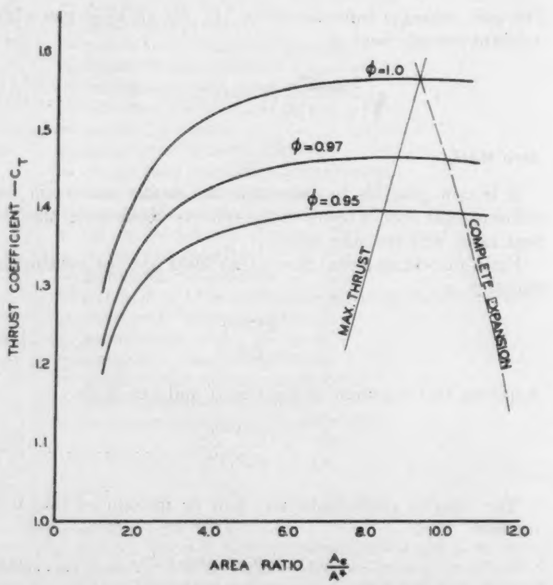


Fig. 2 Thrust coefficient vs. area ratio for 15-deg exit semiangle conical nozzle with uniform velocity coefficients. Over-all pressure ratio 0.012; specific heat ratio 1.25

Mass Flow Efficiency

The increase in entropy measured by the velocity coefficient also causes a reduction in mass flow rate for a given nozzle throat area when compared with an ideal isentropic flow. The mass flow efficiency is defined as the ratio of the actual mass flow rate to the insentropic mass flow rate for a given throat area and nozzle inlet stagnation condition.

The relation between the throat velocity coefficient and the mass flow efficiency can be developed, based on the previously stated simplifying assumptions. For an ideal gas the actual mass flow rate is given by

$$\dot{m} = \frac{NA^*V^*P^*}{\bar{R}T^*} \quad \text{.....[18]}$$

where P^* is the actual throat pressure. The isentropic mass flow rate, similarly, is given by

$$(\dot{m})' = \frac{NA^*(V^*)'(P^*)'}{\bar{R}(T^*)'} \quad \text{.....[19]}$$

where the primed quantities are those resulting from isentropic flow from inlet to throat. Since both the actual and ideal throat velocities are assumed to be sonic for the same stagnation temperature, the actual and ideal throat temperatures are also equal, and the mass flow efficiency, defined as the ratio of Equations [18] and [19], becomes

$$\eta_m = \frac{P^*}{(P^*)'} \quad \text{.....[20]}$$

Dividing numerator and denominator by the inlet stagnation pressure gives

$$\eta_m = \frac{P^*/P_{t1}}{(P^*)'/P_{t1}} \quad \text{.....[21]}$$

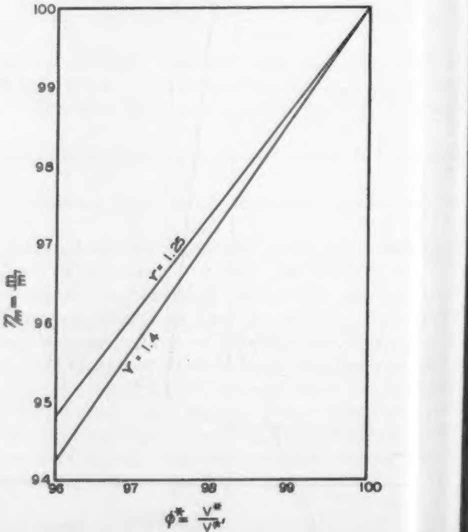


Fig. 3 Mass flow efficiency vs. throat velocity coefficient

Since the denominator is the isentropic pressure ratio for sonic conditions, the following relation applies.

$$\frac{(P^*)'}{P_{i1}} = \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)} \qquad [22]$$

Equation [8] may be solved for the actual pressure ratio in terms of the throat velocity coefficient to give

$$\frac{P^*}{P_{i1}} = \left[1 - \frac{\gamma - 1}{(\phi^*)^2(\gamma + 1)}\right]^{\gamma/(\gamma-1)} \qquad [23]$$

Substituting Equations [22] and [23] in Equation [21] results in

$$\eta_m = \left[\frac{\gamma + 1}{2} - \frac{\gamma - 1}{2(\phi^*)^2}\right]^{\gamma/(\gamma-1)} \qquad [24]$$

Fig. 3 is a plot of mass flow efficiency vs. throat velocity coefficient as determined from Equation [24] for specific heat ratios of 1.4 and 1.25. As shown by Fig. 3, the mass flow efficiency decreases with a decrease in throat velocity coefficient and is always less than the velocity coefficient.

Experimental Program

Equipment and Procedure

The rocket-nozzle test facility used in the experimental program is shown in Fig. 4 and is described in detail in (6). The equipment was designed and instrumented to obtain the following performance characteristics: thrust, thrust coefficient, thrust efficiency, mass rate of flow, mass flow efficiency, specific thrust, and specific thrust efficiency. The performance characteristic of primary interest in this investigation was that of the thrust coefficient.

The blow-down test apparatus consisted basically of a large balance system. The air tanks which supply the nozzle to be tested were balanced through flexure hinges by a counterweight so that changes in weight of air in the tanks could be measured by means of a hydraulic bellows as shown in Fig. 4. Dry, high-pressure air in the tanks was discharged through the nozzle by means of a quick, smooth-opening valve.

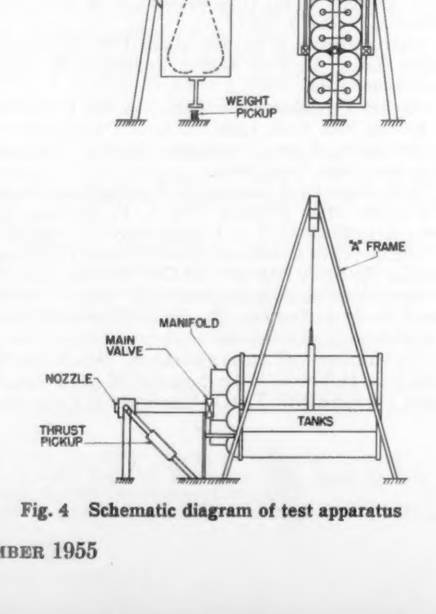


Fig. 4 Schematic diagram of test apparatus

Instrumentation was provided for obtaining the following quantities during the test period: thrust, weight of the air tanks, tank pressure, nozzle inlet total pressure, nozzle inlet total temperature, and time. The instrument panel was photographed at $^1/_2$-sec intervals to obtain the data. The location and method of nozzle attachment shown in Fig. 4 were designed to effectively eliminate any vertical force developed by the thrust system from being transmitted to the weight readings and to prevent nonaxial thrust components from affecting the weight readings.

The thrust system consisted of a hydraulic bellows installed in a 45 deg member mounted between the nozzle and the floor. All pressure gages were 16-in. Heise bourdon gages activated by hydraulic pressure. Air-to-oil pressure transmitters were provided in the nozzle inlet and tank pressure lines to reduce time lag in these systems. Nozzle inlet total temperature was measured by two thermocouples in the straightening tube upstream of the nozzle whose output was fed through a galvanometer to a recording oscillograph.

All tests were run with 1000 psi initial tank pressure, and the data reported are those for a nozzle inlet total pressure of 400 psi. A test consisted of opening the main valve smoothly to prevent oscillations of the balance system and allowing the tanks to discharge through the nozzle being tested. After flow was initiated, the instrument panel was photographed at $^1/_2$-sec intervals for approximately 30 sec. At least three tests were run on each nozzle configuration tested and frequent calibrations of the thrust and weight systems were made during the tests. The reproducibility of test data was within $^1/_2$ per cent.

Test Results

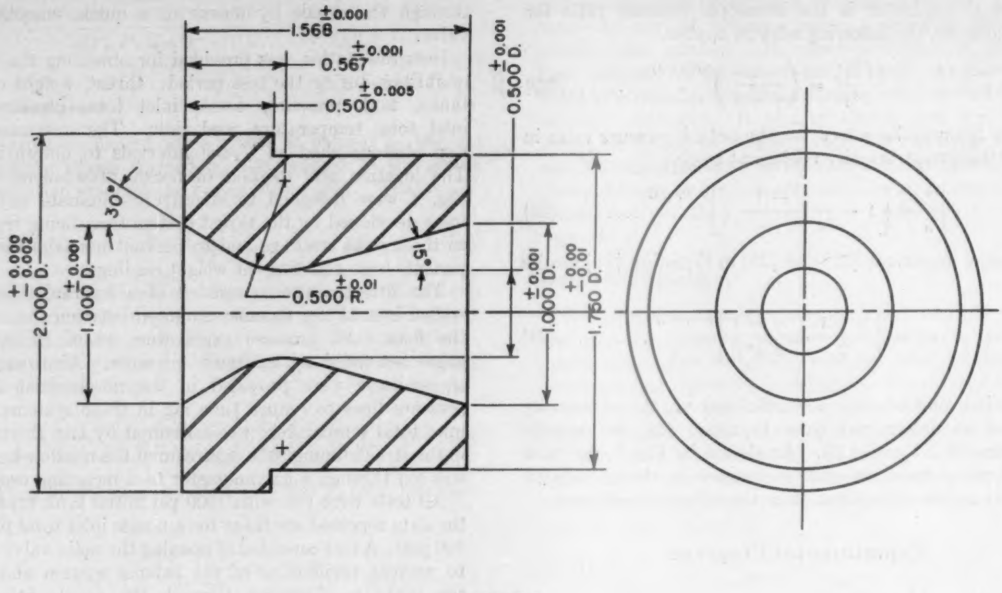
The nozzles tested were similar to that shown in Fig. 6. Two basic nozzles were tested, one having an average surface roughness of less than 20 microin., and the other having an average surface roughness of 300 microin. The area ratio of the nozzles tested was varied by machining the nozzle exit plane normal to the nozzle axis. Area ratio of 6, 4, $3^1/_2$, 3, $2^1/_2$, 2, and 1 were tested for both smooth and rough nozzles. The thrust coefficients were determined from experimental data and the results are plotted vs. area ratio in Fig. 6. Also shown in Fig. 6 are theoretical curves of thrust coefficient vs. area ratio for an over-all pressure that would produce complete expansion at an area ratio of 4 for isentropic flow.

As shown in Fig. 7, the tests of the smooth nozzle closely follow the curve for a uniform velocity coefficient of 98 per cent, while the tests of the rough nozzle closely follow the curve for a uniform velocity coefficient of 97 per cent. These results are of interest for the following reasons: First, they are in excellent agreement with the theory presented in the preceding section using uniform velocity coefficients, and show maximum values at area ratios less than those for complete expansion. Second, the numerical values of the velocity coefficients, even for the rough nozzle, are considerably higher than those stated as the maximum attainable in the widely accepted report of Kisenko (7).

Discussion

The velocity coefficients reported in (7) are based on the assumption that the flow from inlet to throat is isentropic and that all losses occur between the throat and the nozzle exit. The test data reported in (7) are actually the thrust efficiencies rather than the velocity coefficients, since it is assumed that the mass flow efficiency is 100 per cent, which is not the case.

In the preceding section a definite relation is shown to exist between the throat velocity coefficient and the mass flow efficiency as given by Fig. 3. This figure shows the mass flow efficiency will be less than unity if the throat velocity



NOZZLE Ic

Fig. 5 Detail of nozzle

coefficient is less than unity, and a part of the reduction in thrust from that of isentropic flow can be attributed to the reduction in mass flow. The measured mass flow efficiencies for the nozzles reported here were 98 and 96 per cent, respectively. These efficiencies are in good agreement with the velocity coefficients of 98 and 97 per cent, as shown in Fig. 3.

The theoretical analysis of this report is a one-dimensional solution to a three-dimensional problem, and as such is only approximate. This theoretical approach has been shown by this investigation to give excellent agreement with experimental results for the nozzles tested. These nozzles had a

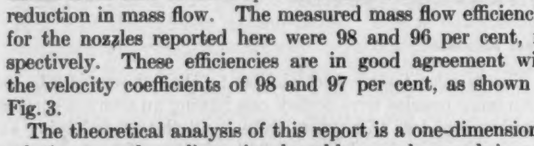


Fig. 6 Thrust coefficient vs. area ratio showing theoretical curves and experimental points

30 deg inlet cone semiangle, a throat radius to throat diameter ratio of unity, and a 15 deg exit cone semiangle. Apparently for these nozzles all changes in the flow are gradual, and three-dimensional effects in the region of the throat are not significant. It is shown in (9), however, that inlet angles larger than 30 deg and throat radius-to-diameter ratios of less than unity may have a measurable effect on nozzle mass flow characteristics with no change in specific thrust (thrust per unit mass per unit time).

The efficiencies reported are for small nozzles in the absence of appreciable heat transfer and therefore do not necessarily represent typical values for large nozzles with a high rate of wall cooling, since no attempt has been made here to establish scale effects.

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Flight Measurements of Aerodynamic Heating and Boundary Layer Transition on the Viking 10 Nose Cone

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Supersonic convective heat-transfer coefficients were measured on the nose cone of Viking 10, fired May 7, 1954, over a Mach number range of 1.20 to 5.28 and a Reynolds number range 5.6×10^4 to 10.45×10^6. Boundary-layer transition was detected and correlated with the Van Driest theory.

Introduction

JET aircraft and missiles are now flying at velocities high enough in the supersonic regime to experience an excessive rise in surface temperature due to the conversion of some of the kinetic energy of the vehicle into heat by compression and friction in the boundary layer. To prevent this "thermal barrier" from setting an upper limit on plane and missile performance, it is necessary to be able to predict this temperature rise for a particular design configuration in order that structural failure, melting, fuel evaporation, and other "thermal barrier" effects can be prevented in the final design. At present, it is very difficult to predict the temperature rise on a particular plane or missile. Because of the urgency of the problem, much recent theoretical work has been done on aerodynamic heating, but relatively little flight data—particularly at high Mach numbers—have been available for correlation with theoretical prediction. The experiment performed in Viking 10 on May 7, 1954, was designed to add to the small store of flight measurements of aero-heating and free-flight boundary layer transition.

In order to predict this in-flight temperature rise, it is necessary to know the temperature recovery factor, the local heat-transfer coefficient, and the conditions for boundary layer transition. Except for the work of Fischer and Norris (1)[2] on V-2 rockets No. 19 and No. 27, Sternberg (2) on V-2 No. 61, and NACA (3), very few free-flight measurements of heat transfer coefficients under transient flight conditions have been made. Most of the experimental investigations of boundary layer transition have been conducted in wind tunnels, (e.g., Czarnecki and Sinclair, NACA RM L53I18a) where there is reason to believe that local shocks, tunnel turbulence level, and angularity of the tunnel airstream may affect the supersonic transition data.

The object of the present study was to correlate the state of the boundary layer determined from flight data with the Van Driest condition for complete stability of the laminar boundary layer (4).

Local supersonic convective heat-transfer coefficients, derived from resistance-thermometer measurements at twenty-two points on the inner surface of the Viking No. 10 nose cone, were correlated nondimensionally with current theoretical solutions and found to agree within the accuracy of measurement. The ratio of measured wall temperature to local stream temperature was plotted vs. local Mach number for turbulent, transition, and laminar flow, and the Van Driest stability curve was found to define closely the region of complete stability.

The principal assumptions on which the analysis was based were:

1. The "thin skin" assumption for the Viking nose; i.e., infinite heat conduction through the skin and zero conduction along it.
2. The validity of the M.I.T. conical flow tables (5).
3. The atomospheric temperature, pressure, and density as summarized by the Rocket Panel (6).

Description of the Experiment

The rocket which carried the test cone was the RTV-N-12A Viking (Fig. 1). This Viking is a research test vehicle which has been designed and developed to provide a platform for experimentation at high altitudes (7). Its airframe is a cone-tipped cylinder with four delta-planform fins. Propulsion is provided by the XLR10-Rm-2 liquid propellent rocket engine, which produces a thrust of 21,000 lb at sea level. The

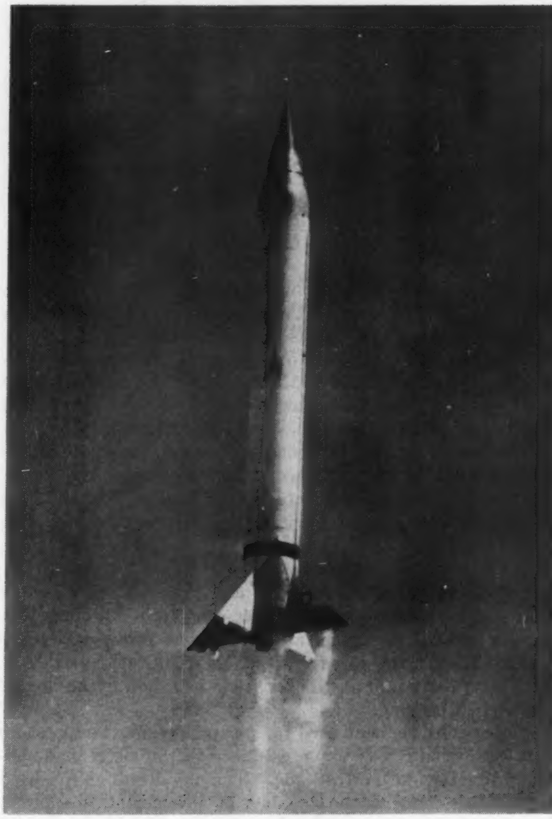

Fig. 1 Viking 10 shortly after take-off

Presented at the 25th Anniversary Spring Meeting of the American Rocket Society, Baltimore, Md., April 20, 1955.

[1] Physicist, Rocket Development Branch.

[2] Numbers in parentheses indicate References at end of paper.

propellants, liquid oxygen and ethyl alcohol, are fed to the engine by a turbopump driven by the decomposition products of high-concentration hydrogen peroxide. During powered flight, the rocket is stabilized in pitch and yaw by swiveling the engine in a gimbal mount. Roll control is provided by small hydrogen peroxide motors mounted outboard in the fins. During coasting flight, other small hydrogen peroxide motors provide stabilization. The Viking is capable of reaching Mach numbers greater than 5 at approximately 200,000 ft in upward flight.

A special conical nose (Fig. 2) for the Viking 10 temperature measurements was designed and manufactured by the Naval Research Laboratory. Stainless steel (A.I.S.I. 304) was selected as the material for fabrication of the cone for several reasons:

1. The structural strength of steel permits the use of a thin skin. This is consistent with the requirement that infinite heat conduction exist through the skin in a normal direction.
2. The coefficient of thermal conductivity for stainless steel is relatively low, which is desirable to minimize the longitudinal flow of heat along the cone.
3. The high structural strength also permits a shell design not employing rings or stringers which would act as heat sinks and disturb the temperature distribution on the skin.

The tip was machined from bar stock. The first $1^{27}/_{64}$ in. of the tip was solid, and the thickness of the rest tapered from $^{1}/_{8}$ in. to $^{1}/_{32}$ in. where it was welded to the rest of the cone, whose semiapex angle was 12.5 degrees. The remainder of the cone was formed from two sections of 0.031-in.-thick stainless steel with a forming brake and welded together. Great care was taken with the tip-to-shell weld and with the two longitudinal welds joining the cone sections to insure that the air flow would not be disturbed by a rough junction.

A boundary layer "trip" was spotwelded to the nose cone 24 in. from the tip and extended 3 in. around the cone (Fig. 3). The purpose of the "trip" was to promote turbulence over that section of the skin shadowed by it.

The entire cone was polished and pressure tested to 15 psi. No measurements of surface roughness or emissivity were taken. The original aluminum cone furnished by the Glenn L. Martin Company with Viking 10 was truncated at an OD of 25.14 in. and the test cone attached by an O-ring sealed bolting ring.

The sensing element used for measuring skin temperature was a modified BN-1 stikon resistance thermometer manufactured by Ruge-de Forrest, Inc. The modifications consisted primarily in reducing the thickness of the element by approximately 30 per cent, resulting in a time constant on the order of 0.1 sec, and in the use of a better resistance-element wire whose resistance-temperature coefficient is essentially constant up to 1000 F. The gages were calibrated in an electric oven against a standard thermocouple (Table 1). The measured temperature coefficient of resistance was 0.0043 per °C, a sensitivity of approximately 2° C per ohm.

Table 1 Resistance thermometer locations

Side of cone	Distance from vertex, in.
Northwest	15, 20, 26, 32, 38
Northeast	15, 20, 26, 32, 38
Southwest	20, 26, 32, 38
Southeast	15, 20, 26, 32, 38

The gages were part of a simple voltage-divider network which presented 0 to 5 volts full-scale output to telemetering. The current through the gages was kept low to minimize heating of the surrounding skin and current was passed through each gage for only $^{1}/_{30}$ sec every sec. The signal output was fed to the NRL 30-channel radio telemeter and recorded by three ground stations.

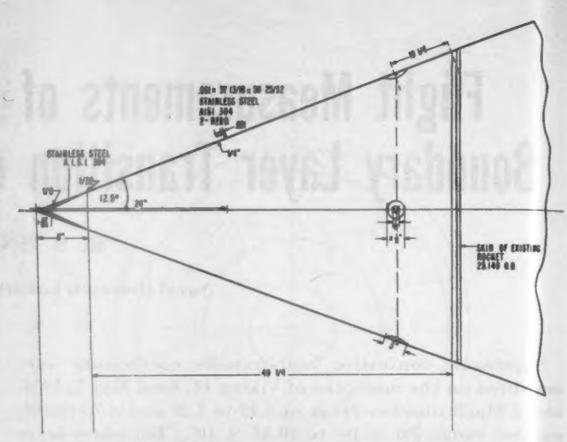

Fig. 2 Sketch of Viking 10 nose cone

Fig. 3 Boundary layer trip on northeast side of cone

Trajectory information on Viking 10 was obtained from a variety of sources. Probably the most accurate of these was DOVAP (Radio DOppler Velocity And Position). DOVAP furnished the rocket space position over the trajectory from 20.5 sec through 300.0 sec. Velocities were found by using a five-point, least-mean-square-fitted polynomial over 1.0 sec intervals. Optical position data were obtained from Bowen-Knapp and from Askania Cine-Theodolite stations. Velocities were found from the Askania data using the same polynomial formula. Radar I "C" station also tracked the rocket and furnished position and velocity data (Fig. 4). All of the altitude data are plotted together as a function of flight time in this graph and (Fig. 5) all of the velocity-vs.-time data are summarized, for powered flight, in this figure. All of the data from these independent sources showed excellent agreement for Viking 10. For the Viking 10 included cone angle of 25°, the shock wave is attached to the cone vertex at a free-stream Mach number of 1.07 which corresponds to a time of 46.5 sec.

Data Reduction Procedure

Using the skin as a calorimeter, the measured convective heat transfer coefficient is the thermal capacitance of the skin, $c_p \rho \tau$, times the first time derivative of the wall temperature, divided by the "thermal potential," the difference between the adiabatic wall temperature and the measured wall temperature (Table 2). The thermal capacitance, $c_p \rho \tau$, is determined by the skin material. The time rate of skin-temperature rise can be determined from the telemeter

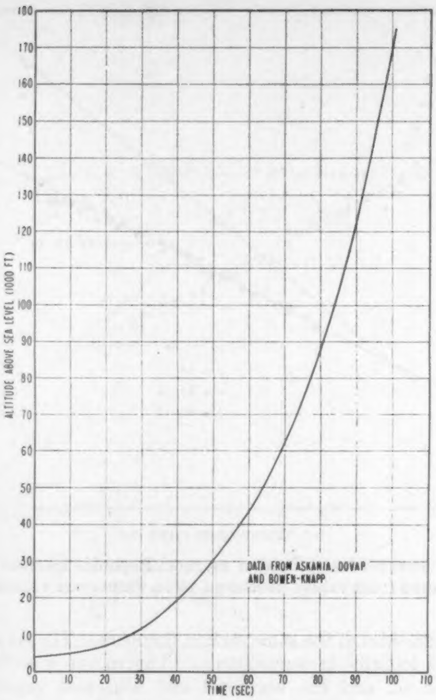

Fig. 4 Altitude above mean sea level vs. time

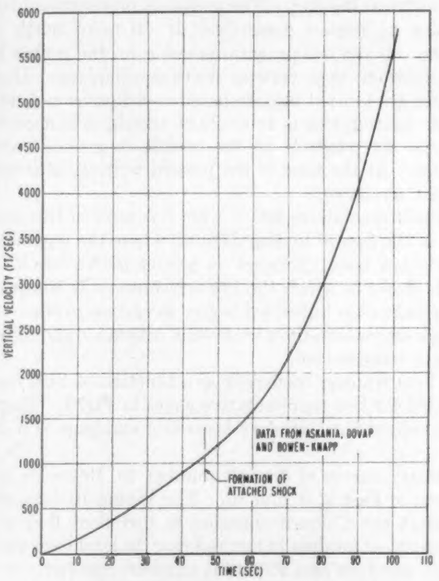

Fig. 5 Vertical velocity vs. time

flight data of transient skin temperature as a function of time. The method of obtaining this derivative deserves some discussion, since the heat transfer coefficient is directly proportional to it.

It was feared that taking slopes from a large-scale graph of temperature vs. time would introduce excessive scatter, and an attempt was made to calculate the derivative numerically by the method of least-square-fitted polynomials. Taking successive differences of the measured temperature indicated that the data could be fitted by a third-degree polynomial. The two remaining variables were the number of points used in calculating dTw/dt for each time and the time interval, Δt. Five points were arbitrarily selected to reduce the time

Table 2 Calculation of heat transfer coefficients and adiabatic wall temperature

1. Heat transfer coefficient:

$$h = \frac{c_p \rho \tau (dTw/dt)}{T_{aw} - Tw}$$

where

c_p = specific heat of skin (0.11 Btu/lb-°F)
ρ = specific weight of skin (501 lb/ft^3)
τ = thickness of skin (0.00258 ft)
dTw/dt = rate of skin temperature rise (°F/sec)

2. Adiabatic wall temperature:

$$T_{aw} = T_1 + r(T_0 - T_1)$$

where

T_1 = local temperature outside b.l. (°R)
r = temperature recovery factor
= $\sqrt{Pr}$ for laminar flow, where $Pr = f(T_1)$
= $\sqrt[3]{Pr}$ for turbulent flow, where $Pr = f(T_1)$
Pr = Prandtl number evaluated on T_1 basis

Table 3 Calculation of Nusselt number and Reynolds number

Nusselt number:

$$Nu = 3600 \frac{Jhx}{k}$$

where

Nu = Nusselt number (dimensionless)
J = mechanical equivalent of heat (778 ft lb/Btu)
h = heat transfer coefficient (Btu/ft^2 sec °R)
x = distance from vertex (ft)
k = coefficient of thermal conductivity (ft lb/ft hr °R)

Reynolds number:

$$Re = \frac{\rho_1 v_1}{g\mu}$$

where

Re = Reynolds number (dimensionless)
ρ_1 = local air density (lb/ft^3)
v_1 = local air velocity (ft/sec)
g = acceleration due to gravity (32.2 ft/sec^2)
μ_1 = viscosity of air (slugs/ft sec)

spent in computation. The effect of increasing Δt is to reduce the amplitude and slightly increase the frequency of the scatter in the derivative. The time interval of $\Delta t = 5.0$ sec was selected by plotting a family of curves of dTw/dt vs. Δt for five different times along the trajectory. Five sec was selected as the interval over which the derivative was least sensitive to changes in Δt over the whole trajectory. This is the same formula employed for finding velocity from position data and corresponds to fitting a third-degree polynomial by the least-mean-square criterion to five data points each 5.0 sec apart.

The adiabatic wall temperature T_{aw} was found from

$$T_{aw} = T_1 + r(T_0 - T_1)$$

The stagnation temperature rise $(T_0 - T_1)$ was read from a curve of $(T_0 - T_1)$ vs. v_1, considering a variable specific heat of air.

Since all the quantities appearing in the formula for heat

transfer coefficient can be measured or calculated from measured quantities, the heat-transfer coefficient can be calculated for each temperature gage throughout powered flight.

For correlation with existing theory and past measurements, the heat-transfer coefficients were put in nondimensional form as Nu vs. Re, calculated according to Table 3. All of the air properties k, c_p, and μ were evaluated on the basis of the local temperature behind the shock wave just outside the boundary layer, T_1. The local values T_1, ρ_1, and v_1 were found from free-stream values measured by balloon sounding and conical flow theory (5). Further details of analysis may be found in (14).

Experimental Results

A representative time history of measured skin temperature at station 26 can be seen in the graph (Fig. 6). The "trip" can be seen to have had a profound effect in delaying the transition of the flow behind it to laminar. Several factors can account for the lack of exact agreement between the temperatures measured on the northwest, southwest, and

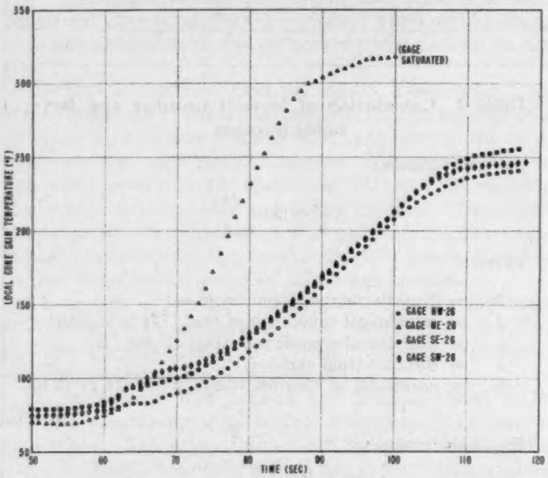

Fig. 6 Cone skin temperature vs. time—measured 26 in. from cone vertex

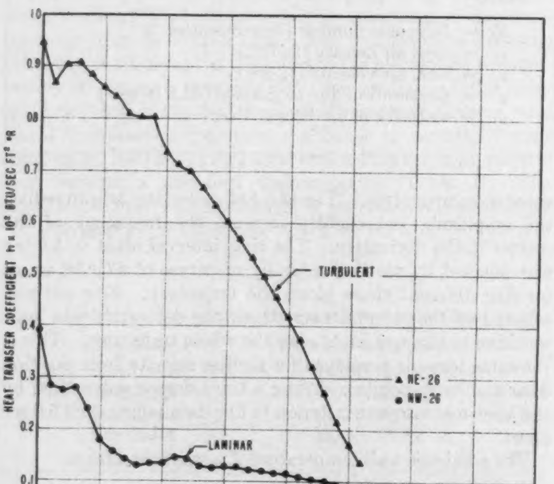

Fig. 7 Comparison of turbulent and laminar local convective heat transfer coefficient

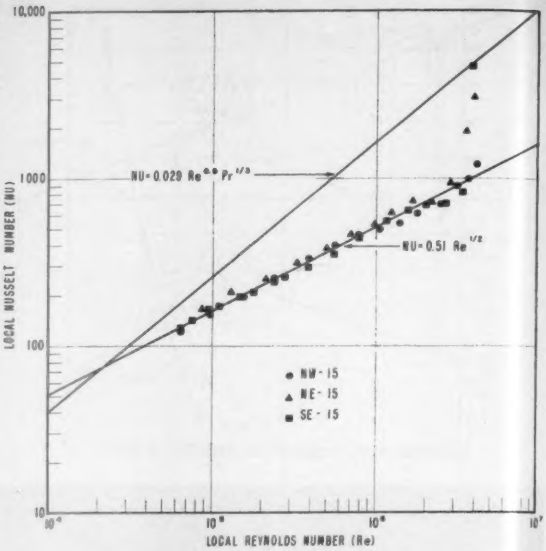

Fig. 8 Local Nusselt number vs. local Reynolds number calculated from values measured 15 in. from cone vertex

southeast sides at the same station numbers. The cone sides differed initially in temperature. The rocket was fired at 10:00 a.m., and the northeast and southeast gages were reading 12 to 20 F higher than those shadowed from the sun. Angle of attack can also be a strong influence in producing unsymmetrical heating. The rocket is programmed by gyro precession to impact approximately 50 miles north of the launcher. While the program is going in, the rocket has an angle of attack in a vertical north-south plane. However, the gages are located in cone-based coordinates and, in order to relate heating effects to angle of attack, it is necessary to determine the attitude of the rocket in ground-based coordinates. At the time of the present writing, attitude data were not available.

Temperatures above 300 F were not used in this analysis, except in the case of finding dTw/dt, where the region of their influence has been indicated on graphs of Nu vs. Re. The bakelite wafer in which the fine resistance-wire temperature-sensing element is imbedded begins to carbonize above 300 F, causing a decrease in the wire-to-skin resistance and indicating too low a temperature.

The heat transfer coefficient as a function of time has been illustrated for two representative gages in Fig. 7. Gage NE-26 was behind the boundary-layer trip and gage NW-26 was not.

Summary curves of Nusselt number vs. Reynolds number are given in Figs. 8, 9, and 10. The Viking 10 data are seen to support the Colburn equation in turbulent flow and the Eber empirical formula in laminar flow, at least over the range of Mach numbers and Reynolds numbers covered.

In Figs. 11 and 12, data from gages on the northwest and northeast sides have been plotted as Tw/T_1 vs. M_1 on a Van Driest curve outlining the region in which the boundary layer should be stable for any Reynolds number. All of the data points indicate that the boundary-layer was stable inside the loop with the exception of the three gages behind the trip.

Conclusions

The probable error in the results is compounded of several main factors. The radiation loss is negligible—less than 1 F/sec for the maximum skin temperature encountered. The temperature lag due to conduction through the skin to the sensing element was approximately ±1.0 per cent. Variation

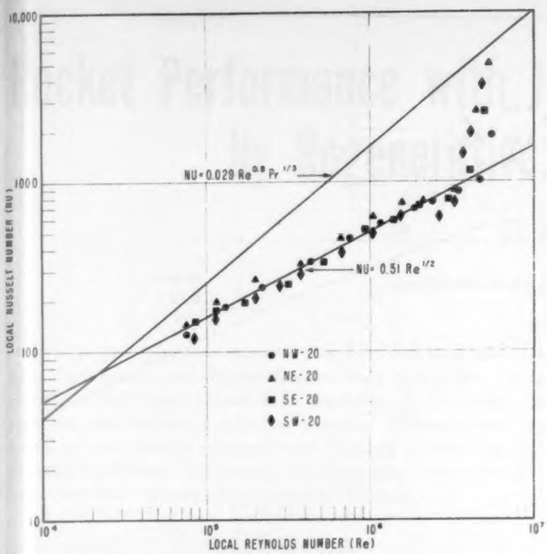

Fig. 9 Local Nusselt number vs. local Reynolds number calculated from values measured 20 in. from cone vertex

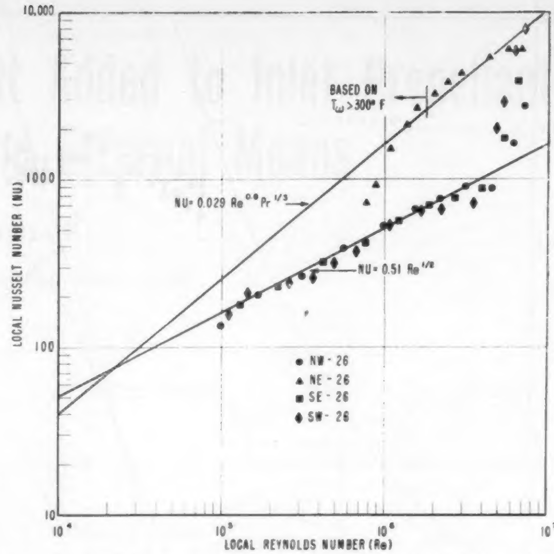

Fig. 10 Local Nusselt number vs. local Reynolds number calculated from values measured 26 in. from cone vertex

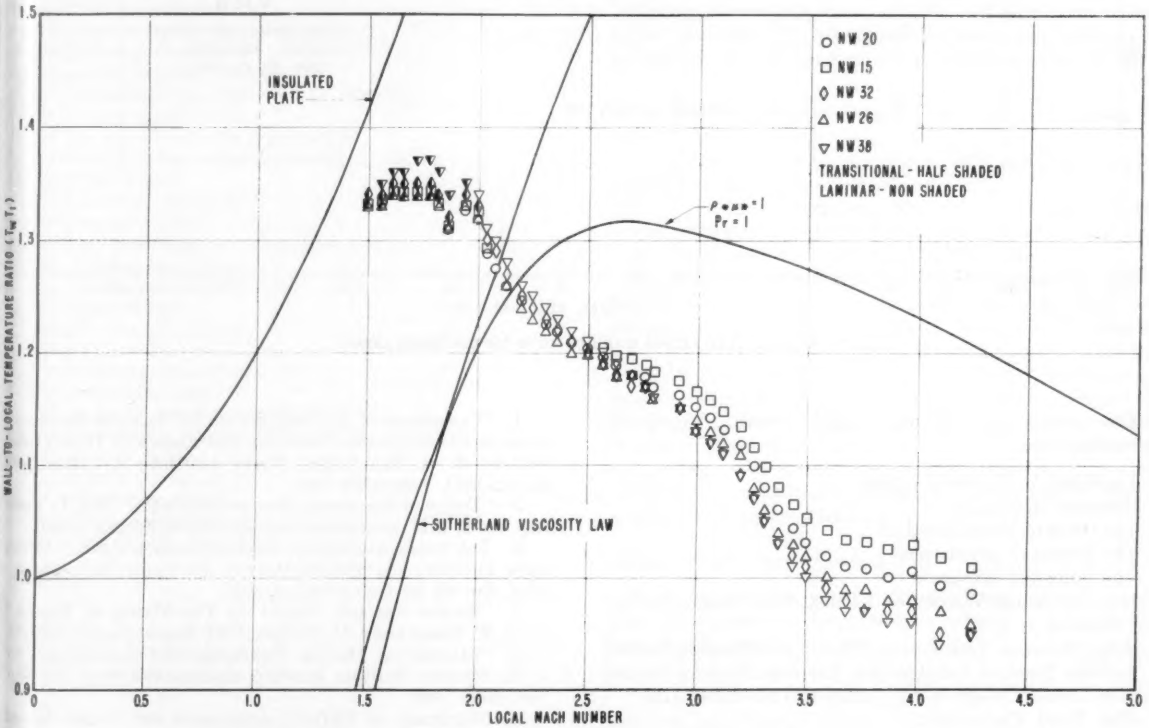

Fig. 11 Van Driest stability curve for northwest gages

in skin thickness amounted to 3.0 per cent. Errors in gage repeatability, telemetering accuracy, and reading error could have contributed an uncertainty of ±3.0 per cent. The total average probable error in heat transfer coefficient is ±7.0 per cent.

Where the Mach number–Reynolds number ranges overlap, the Viking 10 data compare favorably with that obtained on V-2 No. 27 and on RM-10 models by Chauvin and deMoraes. No laminar data for comparison were given in the latter report. Figs. 11 and 12 show good qualitative agreement with the Van Driest stability theory.

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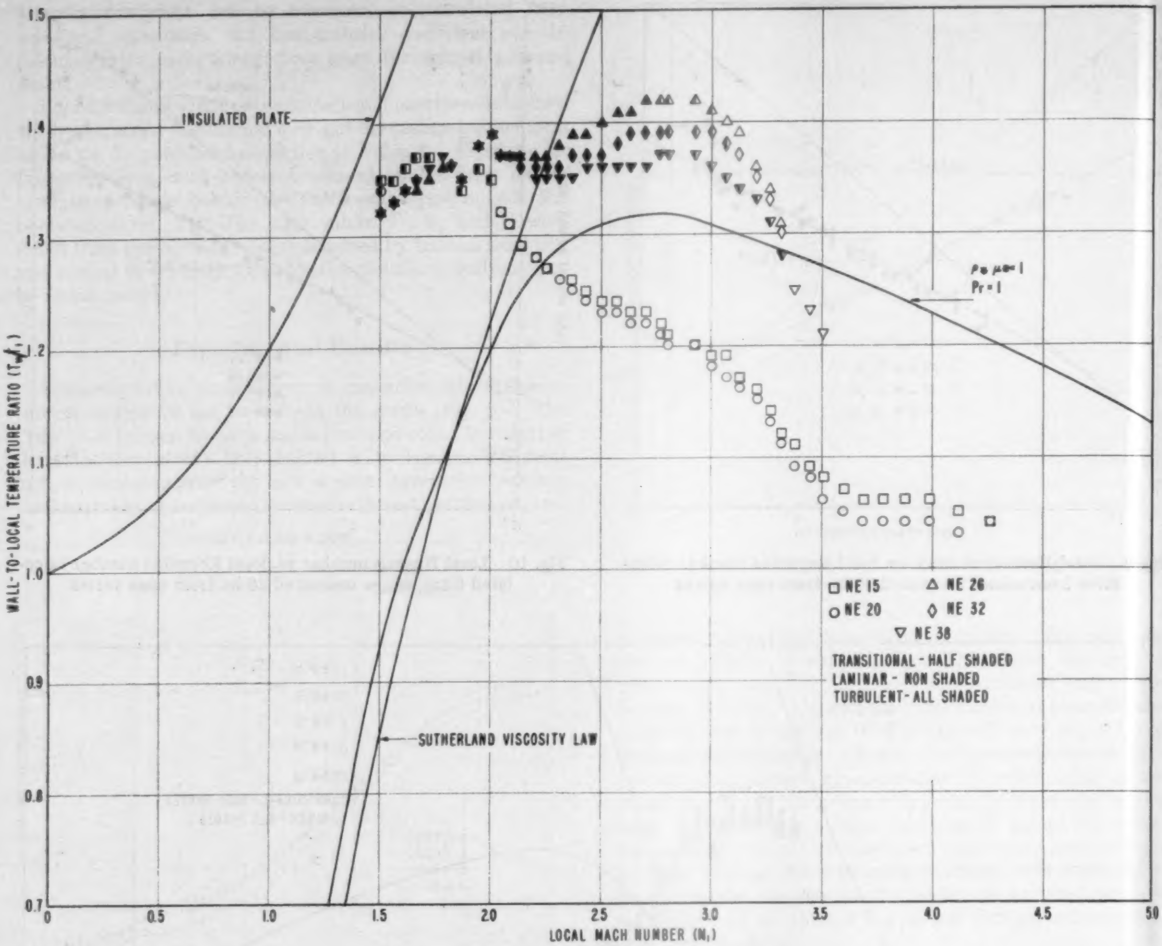

Fig. 12 Van Driest stability curve for northeast gages

The various agencies which made possible Viking 10 operations were:

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The Bureau of Aeronautics
The Bureau of Ordnance
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Army Ordnance Test Station, White Sands Proving Ground
Ballistic Research Laboratories, Aberdeen Proving Ground
New Mexico College of Agriculture and Mechanic Arts
The Rand Corporation

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Rocket Performance with Heat Added to Inlet Propellants by Regenerative and External Means

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This paper presents an investigation of the effects of heating rocket propellants before they enter the thrust chamber, by regenerative heat transfer, by exhaust heat recovery, and from an external source. Calculations were based on simplified assumptions (pure-gas laws and one-dimensional flow dynamics) to determine the effects of heat transfer on the over-all specific impulse.

Nomenclature

A = area, ft^2
C_p = specific heat at constant pressure, Btu/lb °R
D = diameter, ft
f = friction coefficient
g = acceleration due to gravity, ft/sec^2
H = enthalpy, Btu/lb
I_{sp} = specific impulse, lb-sec/lb
J = mechanical equivalent to heat, ft-lb/Btu
k = ratio of specific heats
K = per cent of available exhaust heat
L^* = ratio chamber volume to throat area, in.
M = Mach number
n = polytropic exponent
P = pressure, lb/in.^{2}
ΔQ = heat transferred into propellant, Btu/lb
Q_C = chemical heat, Btu/lb
r = temperature recovery factor
r_p = pressure ratio
R = gas constant, ft-lb/lb °R
T = temperature, °R
T_c = stagnation temperature, °R
T_w = wall temperature, °R
T_{wa} = adiabatic wall temperature, °R
U = over-all heat transfer coefficient, Btu/hr ft^2 °R
v = velocity, ft/sec
V = specific volume, ft^3/lb
W = weight flow, lb/sec
x = distance along flow channel, ft
ρ = mass density, slugs/ft^3

Subscripts

0 = initial
ex = exhaust
int = intermediate
1, 2, 3, etc. = station designations

Introduction

IT IS a common practice in liquid propellant rocket engine design to incorporate regenerative cooling as a means of reducing the effects of extreme heat on surfaces of the thrust chamber which come in contact with the hot gas (1, 2, 3).[2] The cooling effect of the liquid propellants as they pass through the passages in the thrust chamber results in an increase in the propellant temperature and a decrease in the gas temperature. The ideal case generally considered is for ideal isentropic flow (3). However, the object of this analysis was to determine the effect on the over-all performance of the rocket engine resulting from the addition of heat to the propellants. Four different cycles involving heat input into the propellants before they enter the thrust chamber were studied:

1. Regenerative heat transfer without friction during the whole expansion process.
2. Regenerative heat transfer at only one station in the thrust chamber, with no friction.
3. Exhaust heat recovery only, with no friction (this case is similar in results to heating from any outside heat source).
4. Regenerative heat transfer with friction.

In all cases, the heat removed from the expanding gas, or heat source, is used to heat the propellants before they react chemically. Fig. 1 shows a liquid rocket thrust chamber with regenerative cooling along the walls and internal fins from the throat section to the exhaust, to provide the maximum heat-transfer surface for the flow of heat from the expanding hot gases to the liquid propellants. For convenience in comparisons, all calculations are based on the products of combustion of JP-4 and white fuming nitric acid. No attempt has been made to correct for the nonideality of the gas and the effects of dissociation, etc.

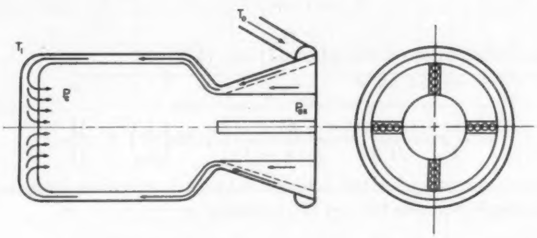

Fig. 1 Thrust chamber schematic drawing

Case 1—Regenerative Cooling Only

With regenerative cooling, the expansion in the thrust chamber is assumed to be polytropic, i.e., internally reversible, but not adiabatic, according to

$$PV^n = \text{const}$$

and

$$\frac{T}{P^{\frac{(n-1)}{n}}} = \text{const}$$

Therefore, the total enthalpy change of the expanding gases in the thrust chamber may be expressed as

$$\Delta H = \int C_p\,dT = \frac{kR}{J(k-1)}\,T_c\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right] \quad \text{[1]}$$

The total work portion during expansion is expressed by the relationship

$$\frac{1}{J}\int V dP = \int \frac{vdv}{gJ} = \frac{nR}{J(n-1)}\,T_c\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right] \quad \text{[2]}$$

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[2] Numbers in parentheses indicate References at end of paper.

Since the difference in the two expressions is the heat removed, we have

$$\int dQ = \Delta Q = \frac{R(n-k)}{J(k-1)(n-1)} T_c \left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right] \quad \text{[3]}$$

The total heat input into the propellants may now be written as

$$Q = \Delta Q + Q_C \quad \text{[4]}$$

which is the sum of the heat removed in heat transfer plus the heat of combustion. The final temperature at the end of combustion will be

$$T_c = T_0 + \frac{\Delta Q + Q_C}{C_p} \quad \text{[5]}$$

and substitution of Equation [3] into [5] gives

$$T_c = \frac{Q_C/C_p + T_0}{\left\{1 - \frac{R(n-k)}{JC_p(k-1)(n-1)}\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right]\right\}} \quad \text{[6]}$$

The expression for the exhaust velocity is obtained by combining Equations [2] and [6], resulting in

$$\frac{v^2}{2g} = \frac{nR}{(n-1)}\left[\frac{(Q_C/C_p + T_0)\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right]}{\left\{1 - \frac{R(n-k)}{JC_p(k-1)(n-1)}\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right]\right\}}\right] \quad \text{[7]}$$

Since the specific impulse for complete expansion is

$$I_{sp} = \frac{v}{g}$$

we obtain

$$I_{sp} = \sqrt{\frac{2nR}{g(n-1)}\left[\frac{(Q_C/C_p + T_0)\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right]}{\left\{1 - \frac{R(n-k)}{JC_p(n-1)(k-1)}\left[1 - \left(\frac{1}{r_p}\right)^{\frac{n-1}{n}}\right]\right\}}\right]} \quad \text{[8]}$$

Fig. 2 shows I_{sp} plotted as a function of pressure ratio and the polytropic exponent, n. Fig. 3 shows the ratio of heat transferred to the heat of combustion for the same conditions as in Fig. 2. Since the calculations do not consider the effects of friction, the results are optimistic. When n is equal to 1.2, for the example, the flow is isentropic.

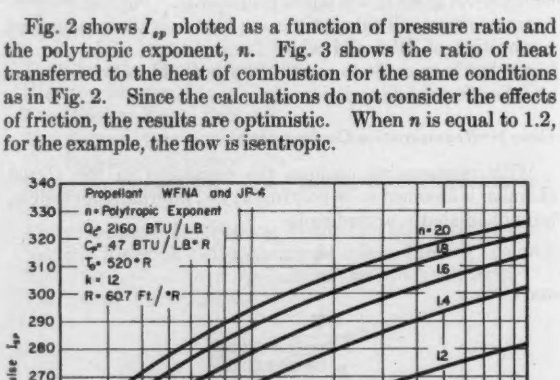

Fig. 2 Specific impulse vs. pressure ratio for varying polytropic exponents

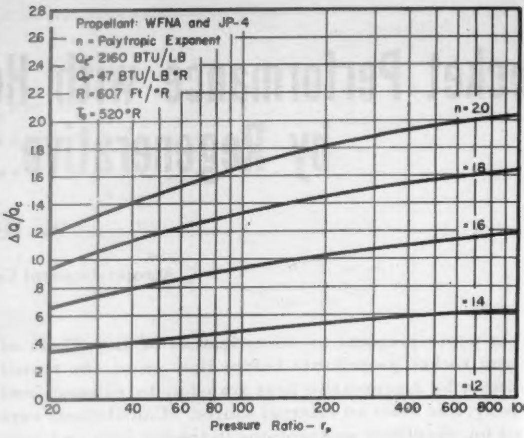

Fig. 3 $\Delta Q/Q_C$ vs. pressure ratio for varying polytropic exponents

Case 2—Regenerative Cooling at Only One Station in Thrust Chamber with No Friction

In considering heat transfer at only one station in the thrust chamber, the example was worked out for the case where the over-all pressure ratio is 30, and the amount of heat removed (ΔQ) at this single station was equal to one tenth of the combustion heat ($0.1Q_C$). The thermodynamic process is illustrated by the solid lines in Fig. 4, where

$$T_1 = T_0 + \frac{\Delta Q}{C_p} \qquad T_4 = T_3 - \frac{\Delta Q}{C_p}$$

$$T_2 = T_1 + \frac{Q_c}{C_p}$$

$$T_3 = T_2\left(\frac{1}{r_{p_1}}\right)^{\frac{k-1}{k}} \qquad T_5 = T_4\left(\frac{1}{r_{p_2}}\right)^{\frac{k-1}{k}}$$

$r_{p_2} = r_p/r_{p_1}$ where r_p is 30 in the example, and $r_{p_1} = P_0/P_{\text{int}}$. The enthalpy changes are

$$\Delta H_1 = C_p(T_2 - T_3)$$

$$\Delta H_2 = C_p(T_4 - T_5)$$

hence

$$I_{sp} = \sqrt{\frac{2J}{g}(\Delta H_1 + \Delta H_2)} \quad \text{[9]}$$

The results of this analysis are shown in Fig. 5 and show I_{sp}, which is a function of r_{p_1}, to increase when the heat is removed progressively further back in the nozzle. When $r_{p_1} = 1$, indicating that the heat transfer occurs right at the entrance of the thrust chamber, $T_3 = T_2$, and temperature, the drop in the chamber is then from T_4 to T_5. For $r_{p_1} = 30$, the heat transfer occurs at the exhaust only. At

$$r_{p_1} = \frac{1}{\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}} = 1.77$$

all of the heat transfer is at the throat of the chamber.

Case 3—Exhaust Heat Recovery (or Heat Recovery from Outside Heat Source) with No Friction

From the previous case it is apparent that most of the gain in I_{sp} comes from removing the heat from the exhaust. In this example, part of the intrinsic energy of the exhaust

stream is transferred to the inlet fluid. The thermodynamic process is illustrated in Fig. 4 by the solid line to T_3 and by the dotted line to T_5.

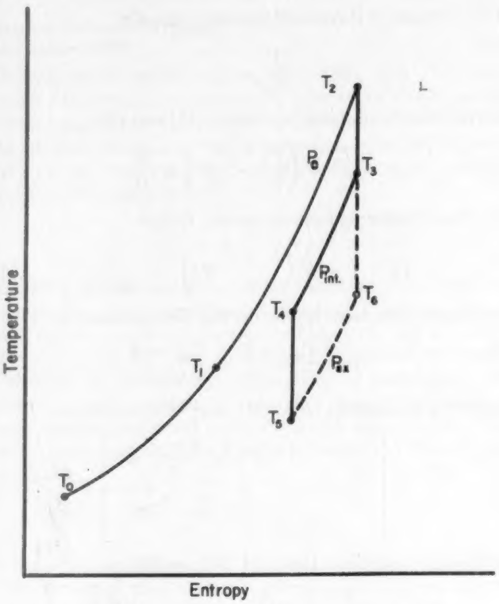

Fig. 4 Temperature-entropy diagram

The heat removed from the exhaust is

$$\Delta Q = KC_p\,(T_6 - T_0)$$

where K is a fraction of the total exhaust heat available between the exhaust temperature and the inlet fluid temperature, T_0.

Since

$$\Delta Q = C_p\,(T_1 - T_0) \qquad [10]$$

and

$$Q_C = C_p\,(T_2 - T_1) \qquad [11]$$

we obtain for the temperature in the thrust chamber

$$T_2 = \frac{Q_C + \Delta Q}{C_p} + T_0$$

$$= \frac{Q_C/C_p + (1 - K)\,T_0}{\left[1 - K\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]} \qquad [12]$$

The exhaust temperature after expansion is

$$T_6 = \frac{Q_C/C_p + (1 - K)\,T_0}{\left[1 - K\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]}\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} \qquad [13]$$

Therefore the total exhaust heat transferred to the inlet propellants is

$$\Delta Q = KC_p\left[\frac{Q_C/C_p + (1 - K)\,T_0}{\left[1 - K\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]}\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} - T_0\right] \qquad [14]$$

The specific impulse is given by

$$I_{sp} = \sqrt{\frac{2JC_p}{g}\,T_2\left[1 - \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]} \qquad [15]$$

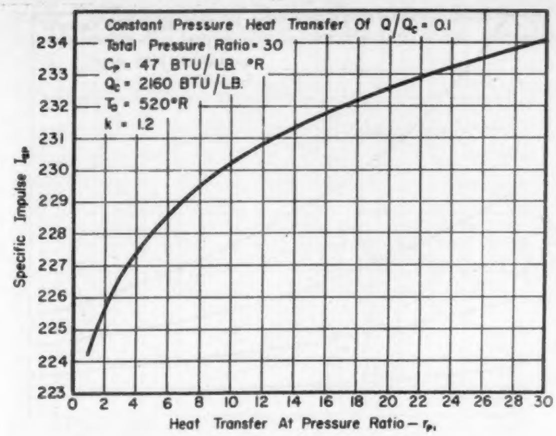

Fig. 5 Specific impulse vs. partial pressure ratio

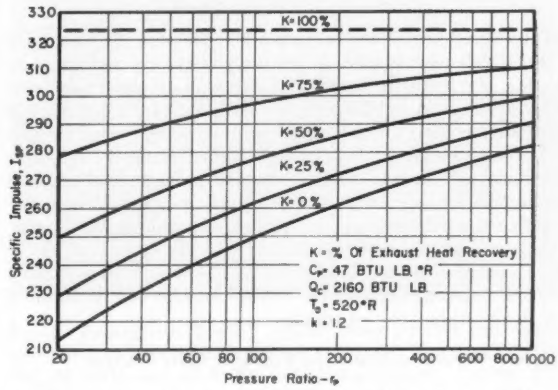

Fig. 6 Specific impulse vs. pressure ratio for exhaust heat recovery

which can be rewritten upon substitution of Equation [12] into [15] as

$$I_{sp} = \sqrt{\frac{2JC_p}{g}\,\frac{[Q_C/C_p + (1 - K)\,T_0]\left[1 - \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]}{\left[1 - K\left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]}} \qquad [16]$$

I_{sp} is plotted in Fig. 6 as a function of pressure ratio for values of K equal to 0, 25, 50, 75, and 100 per cent. For the case where $K = 100$ per cent

$$I_{sp} = \sqrt{\frac{2JC_p}{g}\,(T_2 - T_1)} \qquad [17]$$

It can be seen that for the condition $K = 100$ per cent the specific impulse is independent of pressure ratio and the exhaust velocity is proportional to the square root of the chemical heat input (Q_C). For the case where $K = 0$ (i.e., no heat recovery from the exhaust)

$$I_{sp} = \sqrt{\frac{2JC_p}{g}\,T_2\left[1 - \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}}\right]} \qquad [18]$$

where

$$T_2 = Q_C/C_p + T_0$$

If the curves in Fig. 6 were extended to pressure ratios approaching infinity, it would be noted that values of I_{sp} for $K = 0$ per cent would be greater than values for $K = 100$ per cent. This is because in the former case, use is made

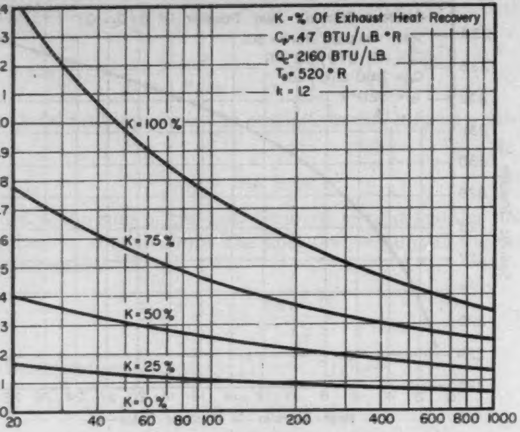

Fig. 7 $\Delta Q/Q_C$ **vs. pressure ratio for exhaust heat recovery**

of the initial heat in the propellants in the example; i.e., $T_0 = 520\ °R$; whereas, when $K = 100$ per cent at very high pressure ratios, the exhaust takes heat away from the propellants that are at an initial temperature of T_0 due to the low value of exhaust temperature resulting from a large pressure ratio. Fig. 7 can be used in conjunction with Fig. 6 for evaluating performance for any form of outside heating, such as heat from missile skin friction and reactor heating. By determining the external heat input and using this as ΔQ, I_{sp} may be determined by working back through Fig. 6.

The results of the analysis of "exhaust heat recovery" show that a significant increase in specific impulse can be obtained with high values of heat transfer.

Case 4—Regenerative Heat Transfer with Friction

This case is of most interest since the phenomena of heat transfer and friction are very intimately associated. The process of heat transfer is complex in that the over-all heat transfer is affected by many factors such as local flow conditions, wall material and thickness, roughness, temperature difference, and film coefficients. In order to avoid some of the complexities it was assumed that the gas conditions were uniform over the cross section and that no resistance to heat flow was offered by the wall thickness or by the liquid propellant. For the analysis, the fluid side temperature was considered as constant since a considerable amount of heat goes into latent heat of vaporization. It was also assumed that the specific heat of the liquid was constant.

The expressions for the change of Mach number and velocity at each station as a function of area change, total temperature change, friction coefficient, and axial length are given by Equations [19] and [20] (4).

$$\frac{dM^2}{M^2} = \frac{-2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dA}{A} + \frac{(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dT_c}{T_c} + 4f\frac{dx}{D}\,\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2} \qquad [19]$$

$$\frac{dv}{v} = -\frac{1}{1-M^2}\frac{dA}{A} + \frac{1+\frac{k-1}{2}M^2}{1-M^2}\frac{dT_c}{T_c} + \frac{kM^2}{2(1-M^2)}4f\frac{dx}{D} \qquad [20]$$

If the heat balance is approximated by

$$WdQ = \frac{\pi}{4}D^2\rho v C_p dT_c = U\pi D\,(T_w - T_{wa})\,dx \qquad [21]$$

and use is made of Reynolds' analogy, namely

$$\frac{U}{\rho C_p v} = \frac{f}{2} \qquad [22]$$

we have, after combining Equations [21] and [22]

$$\frac{dT_c}{T_c} = \left(\frac{T_w}{T_c} - \frac{T_{wa}}{T_c}\right)2f\frac{dx}{D} \qquad [23]$$

From one-dimensional gas dynamics, we get

$$T_c - T = T\left(\frac{k-1}{2}M^2\right) = \frac{v^2}{2gJC_p} \qquad [24]$$

The temperature recovery factor can be expressed as (4)

$$r = \frac{T_{wa} - T}{T_c - T} = \frac{T_{wa} - T}{v^2/2gJC_p} \qquad [25]$$

Combining Equations [23], [24], and [25], we obtain

$$\frac{dT_c}{T_c} = \left[\frac{T_w}{T_c} - 1 + \frac{(1-r)\frac{k-1}{2}M^2}{1+\frac{k-1}{2}M^2}\right]2f\frac{dx}{D} \qquad [26]$$

Combining Equations [19] and [26] results in

$$dM^2 = \frac{M^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\,2f\frac{dx}{D}\left\{(1+kM^2)\left[\frac{T_w}{T_c} - 1 + \frac{(1-r)\frac{k-1}{2}M^2}{1+\frac{k-1}{2}M^2}\right] + 2kM^2\right\} - \frac{2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dA}{A} \qquad [27]$$

Combining Equations [20] and [26] gives

$$\frac{dv}{v} = \frac{2f\frac{dx}{D}\left\{\frac{T_w}{T_c} - 1 + M^2\left[\frac{k-1}{2}\left(\frac{T_w}{T_c} - r\right) + k\right]\right\} - \frac{dA}{A}}{1-M^2} \qquad [28]$$

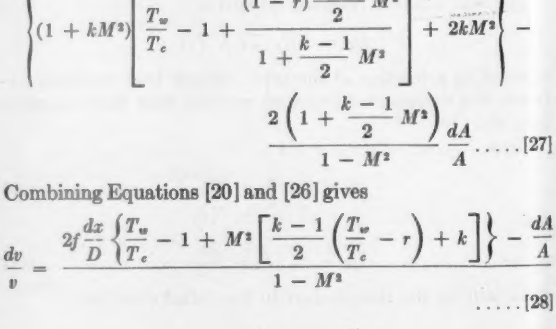

Fig. 8 Specific impulse vs. pressure ratio for varying friction coefficients

To solve Equations [27] and [28], a specific thrust-chamber configuration is required in order to express the cross-sectional areas as a function of length. For an example the following thrust-chamber specifications were chosen:

Thrust	5000 lb
L^*	30 in.
Chamber/throat area ratio	4
Cone nozzle angle	35 deg

A simplification of Equations [26], [27], and [28] can be made if r is assumed to be equal to 1; in other words, complete recovery in the boundary layer. Ordinarily this value is near 0.85 for flat plates. If this assumption is made, variations of T_c are no longer a function of Mach number; therefore, Equation [26] reduces to

$$\frac{dT_c}{T_c} = \left(\frac{T_w}{T_c} - 1\right) 2f \frac{dx}{D} \quad [29]$$

permitting a quick solution to the variation of the total temperature T_c. By a numerical solution of Equation [27], the Mach number at every station is obtained, but in order to solve Equation [27] the initial total temperature must be determined for every varying condition of heat input. This requires a trial method of attack. Having obtained the Mach number and total temperature at each station, Equation [24] may be solved for T and v by use of the Mach number equation

$$M = \frac{v}{\sqrt{kgRT}} \quad [30]$$

The results may be checked by Equation [28], since M and T_c are known at each station, and v may be obtained graphically from Equation [28].

The equation expressing the pressure ratio as a function of Mach number

$$r_p = \left(1 + \frac{k-1}{2} M^2\right)^{\frac{k}{k-1}} \quad [31]$$

was used to determine the pressure ratio at each station.

Fig. 8 shows the I_{sp} for values of the friction coefficient (f) of 0.003, 0.03, and 0.2. Since the total heat flow is directly proportional to the friction coefficient (f) and to the area of friction surface, values of (f) suffice to represent the friction area change, or both, as far as the mechanics of simple heat transfer is concerned. The two under actual conditions would probably give different values of I_{sp} due to separation, etc. Since $\Delta Q/Q_C$ varies along the lines of constant friction coefficient, the theoretical I_{sp} curve for equivalent heat inputs without friction is plotted as a comparison.

The results of the analysis show that no gains in I_{sp} can be expected as a result of regenerative heat transfer with friction, at least with the assumption relating friction coefficient to heat transfer used in this paper.

Conclusions

1. It has been shown that regenerative heat transfer with friction does not increase the I_{sp} despite the fact that regenerative heat transfer without friction indicated a gain in overall efficiency.
2. Gains in I_{sp} can be expected when intrinsic exhaust heat is recovered and put into the incoming propellants. These results are applicable to heat inputs from other sources, such as missile skin friction or reactors.

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2 "Fuel As Coolant," by J. H. Wyld, *Astronautics*, no. 40, April 1938, pp. 11–12.

3 "Rocket Propulsion Elements," by George P. Sutton, John Wiley & Sons Inc., New York 1949, pp. 45–66, 142.

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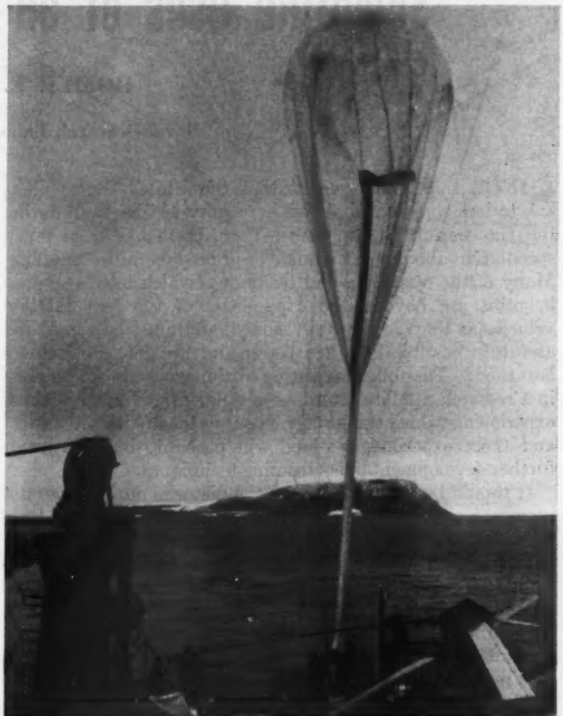

Official U. S. Navy photo

Fig. 5 Photograph showing balloon being inflated and rocket assembled on helicopter flight deck of USCGC Eastwind (WAGB 279) at north end of Baffin Bay (Greenland) in August 1952

Official U. S. Navy photo

Fig. 6 Photograph of Skyhook balloon lifting Deacon rocket at take-off

Scientific Uses of an Artificial Earth Satellite[1]

HOMER E. NEWELL, JR.[2]

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SINCE the announcement that the United States plans to launch artificial satellites for physical research during the International Geophysical Year, there has been much speculation about what actually will be done in the satellite. Many of the researches and techniques which have appeared in print are beyond the capabilities of the first satellite vehicles as they are now envisioned, and must be considered as future possibilities when larger and heavier satellites are launched. The following listing of things which can be done in a research satellite attempts to differentiate between those experiments which can be carried out in the first small "birds" and those experiments which will probably have to await further development of engineering techniques.

It should be emphasized that the pictorial outline does not represent actual plans. It is simply a review of near-term possibilities in the fields of geophysics and astrophysics.

Long-range future possibilities are many. Some are listed in Table 1, and there undoubtedly are many more than those listed here. In fact, the establishment of a new technique and the opening of a new frontier will be just as important a result of the first satellite launching as will the first researches carried out with artificial satellites.

The launching of the first space satellite will be one of the greatest, if not the greatest, philosophical and scientific achievements of mankind.

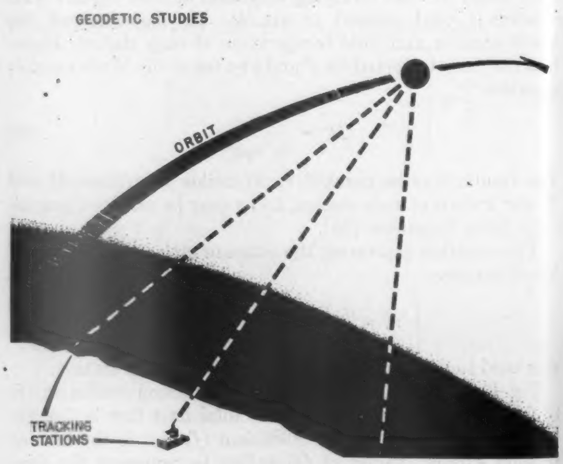
Received Aug. 20, 1955.

[1] Excerpted from a talk by Dr. Newell at the Background Conference on The Development of an Earth Satellite Vehicle, August 16, 1955, at The American Museum-Hayden Planetarium under the joint sponsorship of the AMERICAN ROCKET SOCIETY and the Planetarium.

[2] Head of the Upper Air Research Program, NRL.

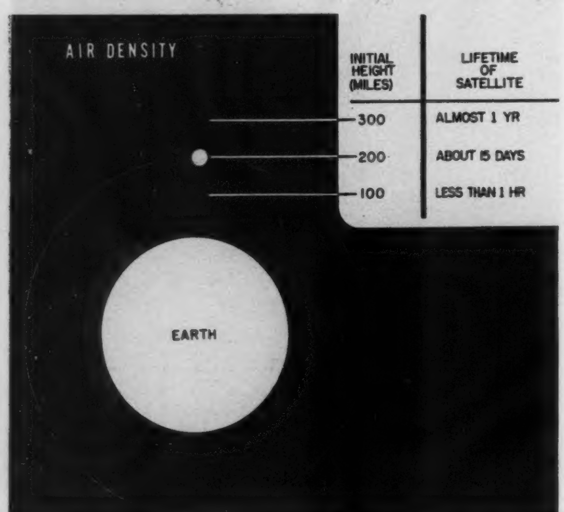
Table 1 Some future possibilities

Photography	Telescopes
Solar batteries	Recovery of satellites
Television	Radio relay
Manned flight	



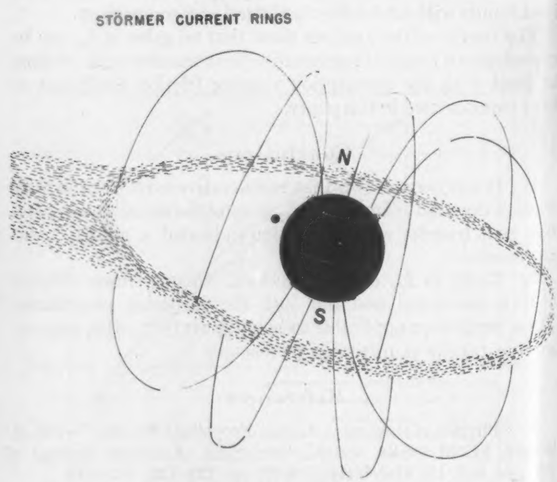
1 Geodetic studies

Purpose: Shape and dimensions of earth. Precise geographical coordinates. Distribution of crustal mass.
Method: Tracking and triangulation.
Practical benefit: Better navigation and mapping.



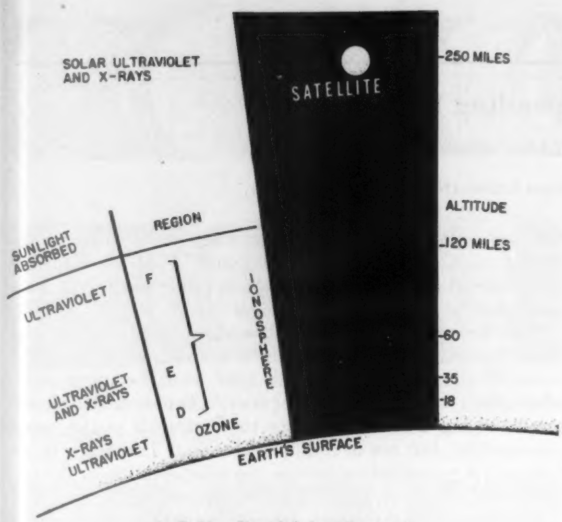
2 Air density

Purpose: Determine amount of air at satellite altitude.
Method: Measure air drag on satellite by tracking.
Practical benefit: Air density fundamental to theory of ionosphere. Also needed for engineering design or high altitude or space flight vehicles.



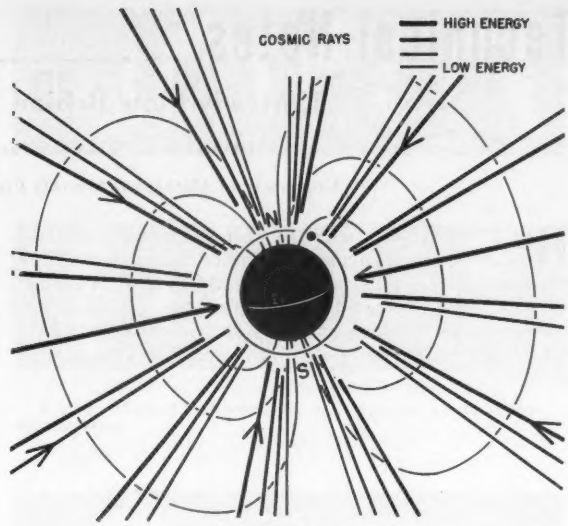
3 Störmer current rings

Purpose: Study electrical currents flowing in and beyond the ionosphere.
Method: Magnetometers and radio telemetering.
Practical benefit: Better understanding of aurora and variations in earth's magnetic field. Better communications.



4 Solar ultraviolet and x rays

Purpose: Measure sunlight before it enters atmosphere. Determine variations in ultraviolet and x-ray intensities caused by activity in sun.
Method: Photon counters and radio telemetering.
Practical benefit: Better understanding of sun, ionosphere, weather, and climate.

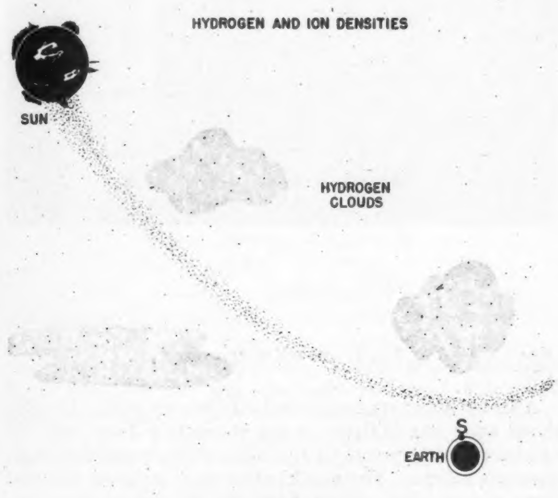


5 Cosmic rays

Purpose: Study the rigidity spectrum, composition, and fluctuations in intensity of the cosmic radiation above the atmosphere.
Method: Particle counters and radio telemetering.
Practical benefit: Better understanding of the sun, aurora, and survival in space.

6 Micrometeorites

Purpose: Study sizes and velocities of micrometeorites.
Method: Particle impact detectors and telemetering.
Practical benefit: Better understanding of ionosphere, zodiacal light, and the dust density in interstellar space.



7 Hydrogen and ion densities

Purpose: Study the emission of particles from the sun, their passage to the earth, and the density of particles in interplanetary space.
Method: Photon counters and radio telemetering.
Practical benefit: Better understanding of the sun, ionosphere, aurora, and magnetic storms.

ARS-IAS Joint Session at IAS Annual Meeting

January 24
Hotel Astor, New York, N. Y.

D. F. FERRIS, of Reaction Motors, Inc., will be the chairman of the ARS-IAS Joint Session to be held on January 24 in conjunction with the Annual Meeting of the Institute of the Aeronautical Sciences, Hotel Astor, New York, N. Y.

The following three papers will be presented at the Session:

Ballistic Missile Performance, by J. William Reece, R. David Joseph, and Dorothy Shaffer, Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y.

Improved On-Off Missile Stabilization, by Robert W. Bass, Princeton University, Princeton, N. J.

Demonstration of Reliability in Liquid Propellant Rocket Engine, by A. G. Thatcher, Reaction Motors, Inc., Denville, N. J.

Technical Notes

Unsteady Flow Behind Expanding Shock Waves

DONALD E. WILCOX[1] and ALEXANDER WEIR, Jr.[2]

University of Michigan, Aircraft Propulsion Laboratory, Ypsilanti, Mich.

RECENTLY, spark schlieren photographs were obtained of shock waves leaving a shock tube and exhausting into the atmosphere. It is the purpose of this note to present some of these photographs illustrating the growth of the spherical shock wave as a function of time as well as indicating the nature of this unsteady convective flow behind these waves.

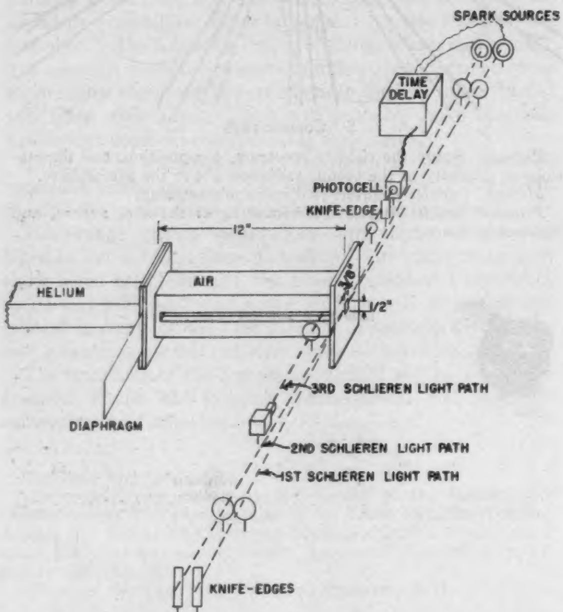


Fig. 1 Sketch of apparatus

A sketch of the apparatus used may be seen in Fig. 1. The shock wave was initiated in the shock tube filled with air at atmospheric pressure by rupturing a diaphragm with high pressure helium. The shock wave thus initiated traveled down the tube and exhausted into the atmosphere where two consecutive schlieren photographs were obtained at time intervals of 6 to 10 microsec between photographs. (A more detailed description of the shock tube used, as well as a discussion of shock tube theory, may be found in Ref. 1 at end of this Note.)

The schlieren light paths crossed at the exit of the shock tube, hence the two consecutive photographs were taken at the same location. A separate (third) schlieren system upstream was used with a photo cell to trigger the time delay circuit which fired the two $\frac{1}{10}$ microsec spark sources.

Thus it was possible to obtain two consecutive pictures of the same shock wave with a known time delay between the photographs. To obtain more than two photographs, it was necessary to repeat the experiment; i.e., obtain two photographs of a different wave at the desired time. By using this technique, the growth of the shock wave could be recorded in a number of photographs. That reproducible results could be obtained, even though different waves were used, may be seen by examination of Fig. 2.

Considering the upper two photographs in Fig. 2, the upper left photograph was taken 54 microsec after the shock wave left the end of the shock tube, and the upper right photograph was taken 7 microsec later. The lower two photographs of Fig. 2 are at the same time intervals as the upper photographs, but are of a different wave. The Mach numbers of the waves before leaving the tube, relative to the undisturbed air, are close to 2.7 in both cases.

The similarity of the two different waves, when compared at the same time, indicates from the reproducibility that it is feasible to treat photographs of different waves as consecutive photographs of the same wave.

Such a series is shown in Fig. 3 where the shock wave is impinging on a flat-nosed probe. In all cases, flow is from right to left. (This series includes the top two photographs of Fig. 2.) The Mach number of the wave as it left the tube was 2.7, relative to the undisturbed air. The times under the photographs are in microsec, time being counted from the emergence of the wave from the tube. Thus the first 120 microsec of growth of the wave can be seen.

Fig. 4 is a similar series of photographs showing a wave impinging on a sharp-pointed probe. Here the time period is the same but the initial Mach number is 2.8.

In these photographs, the presence of a zone emerging from the shock tube behind the shock wave may be observed. In the 26-microsec photograph of Fig. 4, this zone is just impinging on the probe. From a time-vs.-distance plot (characteristic diagram) constructed from the photographic data, it may be seen that the distance this zone lags behind the spheri-

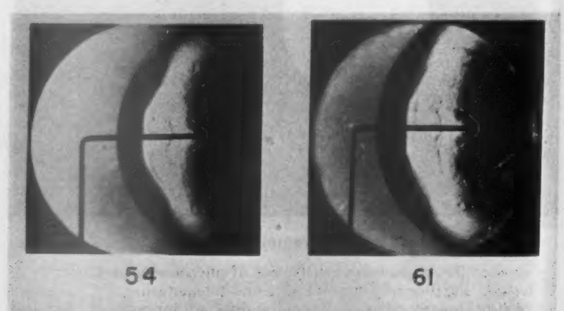


Fig. 2 Reproducible Mach 2.7 shock waves

Numerals indicate time in microseconds.

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[2] Lecturer in Chemical Engineering, Department of Chemical and Metallurgical Engineering and Associate Research Engineer, Engineering Research Institute. Mem. ARS.

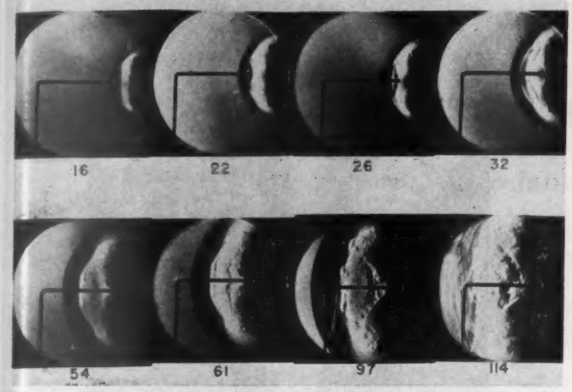

Fig. 3 Mach 2.7 shock wave impinging on flat-nosed probe

Numerals indicate time in microseconds.

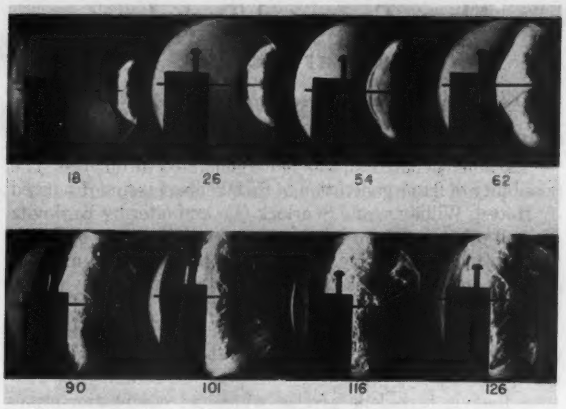

Fig. 4 Mach 2.8 shock wave impinging on sharp probe

Numerals indicate time in microseconds.

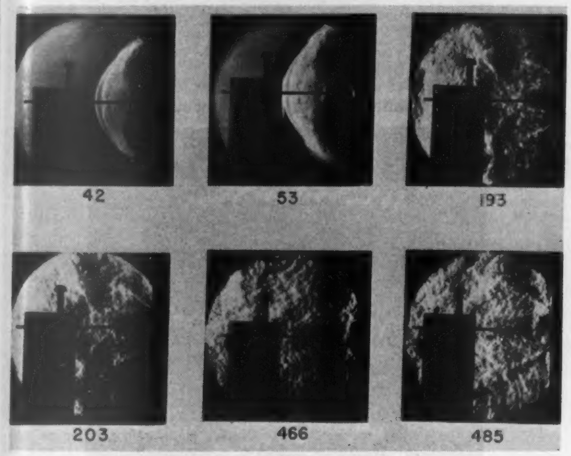

Fig. 5 Flow behind Mach 3.1 shock wave

Numerals indicate time in microseconds.

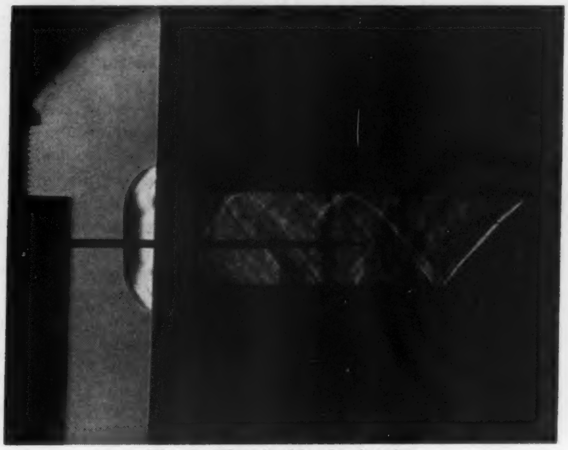

Fig. 6 Flow inside shock tube

cal shock wave increases with increasing time in a surprisingly regular manner. Such a diagram also indicates the expected attenuation of the spherical shock wave in three-dimensional flow.

The nature of this zone was not at first understood. It is not the reservoir gas helium emerging from the tube. One would not expect the helium to appear at all in the 0–126 microsec time interval shown in the photographs of Figs. 3 and 4. The reservoir gas probably travels at slightly under sonic velocity, and for a temperature ratio of 3.5 across the shock wave, the reservoir gas would require about 200 microsec to traverse the 1-ft shock tube length.

Fig. 5 presents a series of schlieren photographs over a much longer time period (up to 485 microsec) at a Mach number of 3.1. Thus, in the 193 and 203 microsec photographs, it is possible that the air-helium interface appears; but that this interface has passed by in 466 microsec and that only helium appears in the 466 and 485 microsec photographs of Fig. 5, are confirmed by the appearance of diaphragm fragments in the latter two photographs.

Thus, the zone which appears only slightly behind the spherical shock wave and moves with a velocity slightly less than that of the shock wave at any time, is not the helium reservoir gas and must consist only of air. The density of this air must be different from the density of the air immediately behind the shock wave since a density gradient was recorded by the schlieren system. It was hypothesized by R. B. Morrison that this zone includes the air which was initially in the shock tube while the air immediately behind the shock is air which was initially in the atmosphere external to the shock tube. Fig. 6 confirms the fact that the air in the shock tube is moving supersonically. The expansion of this air as it emerges from the shock tube results in a different density and hence the zone of demarcation observed in the schlieren photographs.

Acknowledgment

The schlieren systems used, including the $^1/_{10}$ microsec spark sources and the time delay circuit, were designed and constructed by R. B. Morrison, R. E. Cullen, and E. J. Schaeffer for previous work on Project Squid sponsored by the Office of Naval Research. This research was sponsored by the Office of Ordnance Research, U. S. Army.

Reference

1 "A Shock Tube Investigation of Detonative Combustion," by R. B. Morrison, University of Michigan Press, Ann Arbor, Mich., 1952.

Flame Generated Turbulence

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THIS note presents some experimental evidence concerning the much debated topic of flame generated turbulence. The possibility of flame generation of turbulence was first discussed by Hottel, Williams, and Scurlock (1)[2] and later by Karlovitz (2) and others. There has been a certain looseness of definition in what is meant by flame generated turbulence, and this caused considerable discussion at the recent Gas Dynamics Symposium at Evanston, Ill.

Turbulent flow, at a given point in space, is usually characterized by two statistical quantities: intensity and scale. Consider a premixed, homogeneous, combustible mixture that is turbulent and in which no combustion takes place. Assume one knows the intensity and scale of turbulence at each point in the flow. Now, permit combustion to occur in the stream, and consider three regions:

1. Reactants: the unreacted mixture, in metastable thermodynamic equilibrium.
2. Products: the reacted mixture in final thermodynamic equilibrium.
3. Reaction zone: where thermodynamic properties of the stream are significantly different from either the reactants or products.

What happens to the intensity and scale of turbulence in each of these three regions compared to that which existed previous to combustion? Any significant increase may be attributed to "flame generated turbulence." It should be remembered that these three regions of space may vary in time.

In order to attempt to answer the above question the author carried out some experiments at the Combustion Aerodynamics Laboratory at Harvard University. The tunnel is described in (3). A grid was placed over the primary nozzle to generate a turbulent flow of a premixed homogeneous mixture of propane and air. Hot wire measurements of turbulent intensity were made in the propane air mixture and compared with the well-established data on turbulent decay behind grids. The quantitative agreement was good, giving confidence in the measuring techniques.

The turbulent intensity was then carefully measured by a hot wire in a traversing mechanism along a line parallel to, and about 2 in. downstream of the grid. With these data in hand, the mixture was ignited and a flame stabilized on a wire flameholder. The measurement of turbulent intensity was then repeated along the same line using the same hot wire. Fig. 1 shows the turbulent flame. The solid line indicates a typical hot wire traverse and the arrow indicates the flow direction.

The turbulent intensity measured in these tests ranged from 2 to 6 per cent. The grid wire size was changed from $^1/_{64}$ to $^1/_8$ in. diam. All grids were rectangular, interwoven screen types. The mean stream velocity was about 50 ft/sec. The air fuel ratio was varied from lean to rich.

The hot wire probe was a special one constructed for high temperature use. The wire material was 80% platinum, 20 per cent iridium, and was 0.0005 in. diam. The probe was used both as a conventional hot wire (sensitive to both velocity and temperature fluctuations) and as a rapid response resistance thermometer (wire current of about 5 ma). In this way the reaction zone where temperature fluctuations are important can be located accurately.

Fig. 2 shows some typical probe oscilloscope traces. The top two traces represent temperature fluctuations from the reaction zone. The next two traces are turbulent fluctuations from the reactant region. The bottom trace is the equipment noise level.

Fig. 1 Schlieren picture of a turbulent flame

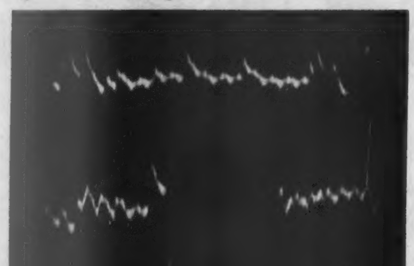

Fig. 2 Hot wire oscilloscope traces

An analysis and comparison of the data indicate the following conclusions:

(a) In the reactant region there is *no* significant increase in the turbulent intensity.

(b) The reaction zone is too complicated to permit any interpretation or conclusion based on these measurements only.

(c) The product zone has some temperature spottiness, but these measurements are qualitative only.

Hence, at least upstream of the reaction zone, there is no significant evidence of flame generated turbulence.

References

1 "Flame Stabilization and Propagation in High Velocity Streams," by Williams, Hottel, and Scurlock; Third Symposium on Combustion, Flame and Explosion Phenomena, 1949, p. 21.

2 "Open Turbulent Flames," by Bela Karlovitz; Fourth Symposium on Combustion, 1952, p. 60.

3 "Boundary Layer Flame Stabilization," by R. A. Gross, JET PROPULSION, vol. 25, June 1955, p. 288.

Received September 15, 1955.

[1] Research Engineer.

[2] Numbers in parentheses indicate References at end of paper.

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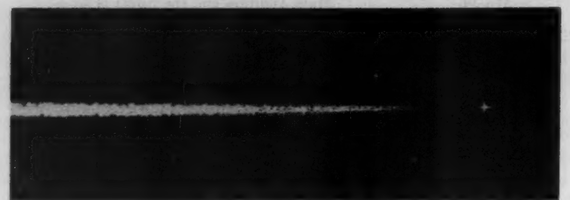
Jet Propulsion News

Alfred J. Zaehringer, American Rocket Company, *Associate Editor*
Norman L. Baker, Indiana Technical College, *Contributor*

Jet Aircraft and Engines

Jet Fighters. An Air Force F-100C Super Sabre set the first official mark at high altitudes (over 35,000 ft) and at a speed faster than sound. An 822.135 mph record was made over an 18-km (11-mile) course on California's Mojave Desert. Runs of 870.627 mph and 773.644 mph were made.



North American Aviation

F-100C sets supersonic speed mark

● A missile-carrying version of the Demon jet fighter is to be the Navy F3H-2M. A development contract for another McDonnell Navy fighter is the F4H-1. Meanwhile, an interceptor version of the Air Force Voodoo, the F-101B, has been ordered by the Air Defense Command. The F-101 is powered by two J-57 turbojets of over 10,000-lb thrust each. Specifications: length, 67.4 ft; height, 18 ft; span, 39.7 ft.

● With the first acceptance of production F-102A, released specifications include: span, 38 ft; length, 68 ft; height, 18 ft. The Convair craft has reached altitudes of 55,000 ft.

● F-104, Lockheed's new supersonic interceptor for U.S.A.F. is reported to have undergone over 150 flight tests. The F-104 is said to be similar in appearance to the X-3 research plane—extreme dartlike construction with short, straight wings. Although no performance details have been released, the maximum speed of the craft is reported at near Mach 2 with a service ceiling greater than 68,000 ft. Presently powered by the J-65 turbojet, eventual power is to come from a J-79 engine.

● New VTO fighter is the Ryan delta-wing XF-109 which is slated for flight tests at Edwards AFB. Power for the VTO craft comes from an afterburner-equipped Rolls-Royce Avon turbojet. Over-all appearance of the ship is batlike.

● Ariete is a new light interceptor developed by Italy which is to receive further development in a joint U. S.-Italy venture. Still further off are three types of new aircraft slated for "Phase I" development for U.S.A.F. A long-range interceptor will be developed by Lockheed, Northrop, and North American. Fighter-bomber contracts are placed with Republic and North American. Douglas and Martin will work on a tactical bomber. Also, U.S.A.F.'s ARDC is reported to have taken over further developments of the Avro Aircraft (Canada) flying-saucer project. So far, Canada admits spending some $0.4 million on developments. A prototype saucer may cost as much as $100 million, according to the Canadian Defense Ministry.

Handley Page

Victor crescent wing bomber

Jet Bombers. Production of Britain's "V" bombers—the Valiant, Victor, and Vulcan—is rapidly building up with a large fleet of the four jet bombers already in service. The Valiant, with performance said to exceed the B-47, is designed to bomb from an altitude of more than 50,000 ft. The V bombers are all able to fly 4000 miles nonstop and can fly at speeds of "only slightly below the speed of sound." Valiants are now being equipped with ATO rockets.

● The new English Electric Canberra jet bomber will operate at 63,000 ft using a new Bristol Olympus turbojet engine. Present altitude for the Mk 9 Canberra is 63,668 ft. A new roundtrip speed record between London and New York was set on August 23 when an R.A.F. English Electric Canberra completed the trip in 14 hr, 20 min. The 3457-mile long west leg was averaged at 481 mph while the east leg was done at 550 mph. The jet flew at altitudes of 30,000–50,000 ft.

Supersonic bomber Hustler, B-58, by Convair is now in production at Fort Worth. The B-58 is to be powered by GE J-79 turbojets.

Jet Transports. M-225 is the new design for a light jet transport by Fairchild Engine & Airplane. Four J-44 turbojets of 1000-lb thrust each will propel the 17,695-lb craft. Specifications: span, 35 ft, 4 in.; length, 50 ft, 10 in.; height, 13 ft, 3 in.; range, 1280 nautical miles. The low-wing transport carries seven passengers and a crew of two.

● Estimates are that the 550-mph DC-8 jet transport will be able to operate profitably down to ranges as low as 500 miles. Douglas had previously announced that the DC-8 would be a high-speed, long-range craft which could fly from Los Angeles to New York in less than 5 hours and from New York to Paris in less than 7 hours. Fuel capacity of the domestic version will be 13,338 gal, intercontinental models will carry 18,538 gal. Payload of the long-range model is to be 32,000 lb. Area of the wings which have a 30-deg sweep is 2594 sq ft. Landing and take-off characteristics similar to piston aircraft is to be provided by a speed brake located beneath the center of the fuselage.

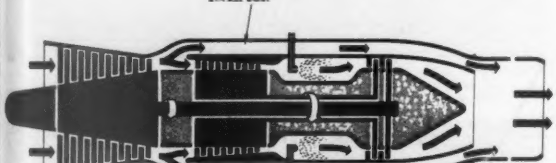
Editor's Note: The information reported in this Section has been selected from approved news releases originating with the Department of Defense, private manufacturers, universities, etc., and from published news accounts in journals and newspapers. The reports are considered generally reliable, although no attempt has been made to verify them in detail.

Douglas Aircraft

DC-8 jet transport

• Convair has released details of its jet transport proposal which strongly resembles the Boeing 707 and the DC-8. The craft is powered by four J-57's in swept forward pods beneath the sweptwings. Because of the advanced state of the Boeing and Douglas jet transport projects, Convair is not expected to continue development.

Jet Engines. By-pass jet engine of 13,000-lb thrust was announced by Rolls-Royce. The Conway engine is slated for the four-engine Vickers V-1000 military transport. In the by-pass engine, some of the compressed intake air by-passes the combustors and enters the nozzle. Working at a high pressure ratio, a final jet containing a greater mass of air moving at a lower speed gives high propulsive efficiency. Lowered jet noise and a low specific fuel consumption are also claimed.



Rolls-Royce

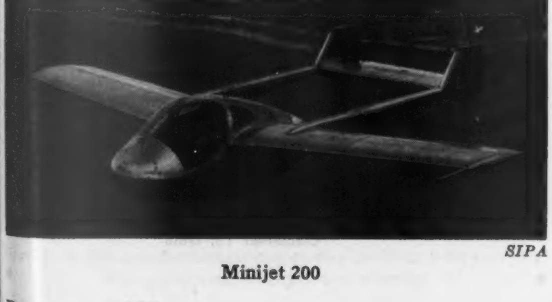
By-pass jet engine

• Westinghouse PD-33 turbojet engine of 6000-lb thrust is aimed for commercial production. PD-33 has a single compressor of 16 stages. Engine has been tested to 50 hr and combustor at simulated altitudes of 95,000 ft.

• Gyron, the high-power turbojet by de Havilland, has started its flight tests in the Short Sperrin four-engine jet bomber.

• Operational status is soon to be attained by the new P&W J-75 turbojet which delivers 15,000-lb thrust.

Small Jets. Minijet, the French SIPA 200, is claimed the first all-metal, two-seater side-by-side light jet airplane



SIPA

Minijet 200

to fly. Main purpose is for liaison and primary training. Of modern construction, the craft is powered by a Turbomeca "Palos" turbojet engine. Specifications:

Span	26 ft, 2 in
Over-all length	17 ft
Height	6 ft
Wing area	104 sq ft
Dihedral	30
Tailplane span	6 ft, 8 in
Turbojet "Palos"	330-lb static thrust (can be supplied with 365-lb static thrust)
Empty weight (fully equipped)	990 lb
Crew (payload)	365 lb
Kerosene and oil	360 lb
Take-off weight	1675 lb
Performance:	
Maximum speed	250 mph
Cruising speed	225 mph
Take-off distance	1000 ft
Take-off distance (to clear 80-ft obstacle)	2000 ft
Range (without tiptank)	350 mi
Range (with tiptank)	470 mi

In addition to tricycle landing gear, the craft features VHF radio, complete instrumentation, cabin cooling and heating, ejectable cockpit, electrical starter, and dual controls.

• Stateside availability of the MS 760 commercial two-jet plane appears good as a result of the recent demonstration tours. Deposits have been received and many corporations have shown interest in the French plane.

• Student is the new two-seat, side-by-side, jet trainer. Designated as the Miles M.100, Student is propelled by a Blackburn-Turbomeca Marbore 2 turbojet rated at 880-lb thrust. Specifications: gross weight, 3100 lb; span, 28 ft; height, 6¼ ft; length, 27 ft; endurance, 3 hr; maximum speed, 300 mph.

Turboprop Aircraft. Turboprops have been making good showings in the news. The first flight test of the XF-84H turboprop fighter plane was successfully completed. The Republic plane, powered by an Allison XT-40-A-1 twin power unit turboprop engine of 5850 eshp, was aloft for 35 minutes at an altitude of 20,000 ft. Service ceiling of the unique craft is reported to be over 40,000 ft with a range of over 2000 miles. Specifications include: span, 33.5 ft; length, 51.5 ft; height, 15.4 ft. The XF-84H, which is to be afterburner-equipped, is said to be the fastest single-engine prop-driven plane ever built.

• Hercules, C-130A, produced by Lockheed Aircraft was placed on the drawing boards early in 1951 with the first flight taking place in August 1954. Hercules carries a crew of four, is able to carry 92 combat-ready troops, or 20 tons of cargo. Power comes from four Allison T56 turboprops of 3750 eshp each, using JP-4 fuel. Provision has also been made for use of eight 15KS-1000 RATO units. With a maximum take-off weight of 110,000 lb, Hercules has a span of 132.6 ft, length of 95.2 ft, height of 38.3 ft.

• Britannia, by British Bristol firm, is due on international routes this year. Powered by four Proteus turboprops, Britannia can carry 100 passengers between London and New York, giving it a speed of 360 mph over a nonstop leg of 3650 miles.

• Viscount, by Vickers-Armstrong has been placed into

regular U. S. service by Capital Airlines. Viscount is powered by four Rolls-Royce Dart turboprops of 1520 eshp each. Viscount has been in regular European service since 1950.

● Dart is Convair's turboprop airliner. The 60-passenger transport is powered by four Rolls-Royce RDa 7 turboprops rated at 2000 eshp each. Cruise speed is 330 mph at 13,000 ft with a maximum range of 1155 miles. Empty Dart weighs in at 38,000 lb; take-off weight is 67,000 lb.

Facilities

THE Naval Air Missile Test Center at Point Mugu, Calif., is to receive a high-speed computer to reduce missile flight and wind tunnel data to forms which can be readily utilized by project engineers. From the raw data collected during testing, a history of all measurable performance characteristics of a missile will be produced, such as thrust, velocity, position at a given time, acceleration, response of control surfaces, etc.

● Another new West Coast computer installation is at the Air Force Marquardt Jet Laboratory in Van Nuys, Calif. A magnetic drum machine will translate pressure, temperature, and fuel measurements as supplied in ramjet development tests. It will also be used in the design and development of ramjet components and accessories. Test data are taken during the ramjet tests and automatically recorded on punched cards. These readings are processed on an IBM computer at a rate of 900 per minute. No other auxiliary equipment is required to process the test data. The final punched cards are then interpreted or typed at a rate of 750 readings per minute. The computer can completely process the IBM cards into calculated form for engineering analysis within two and a half hours after completion of a test run—some five times faster than previous methods used.

● Beech Aircraft Corp. opened a new engineering facility in Boulder, Colo., for work on classified projects. Among the assignments to be undertaken by the 75-man engineering staff are in the missile field.

● Newest research tool at Ryan Aeronautical Co., San Diego, Calif., is a dual purpose test cell which is the nation's first facility to be designed and built for testing jet engines and afterburners in a vertical position. Unique in concept, the new cell can handle turbojets in horizontal and vertical attitudes, as they will operate in vertical take-off aircraft. The facility cost $175,000.

● Mach 18 is the goal set for a new NACA ballistics model range. Cost: $635,000.

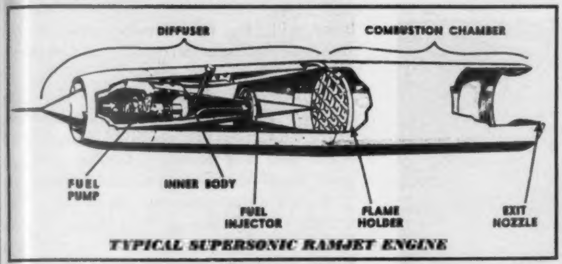
● OMAR is the name of a joint propulsion effort to be exerted by Olin Mathieson Chemical, Marquardt Aircraft, and Reaction Motors. Under the program, RMI and Marquardt will set specifications for rocket propellants and ramjet fuels and Olin Mathieson will undertake research on the desired materials. It was also announced that work is under way concerning the application of some rocket techniques to chemical processing operations.

● High-speed electronic data processing systems total over $0.5 million at the U.S.A.F. Arnold Engineering Center, Tullahoma, Tenn. The set is to be used in the Engine Test Facility, Gas Dynamics Facility, and the Propulsion Wind Tunnel. The fully automatic wind tunnel will measure pressures on jet engines and airfoil sections during the tunnel operation. It can monitor 233 separate pressure points in less than 30 sec with an accuracy of 0.1 per cent. Also to be monitored are force, lift, pitch, drag, yaw, roll, etc.

Schedule of Forthcoming Meetings

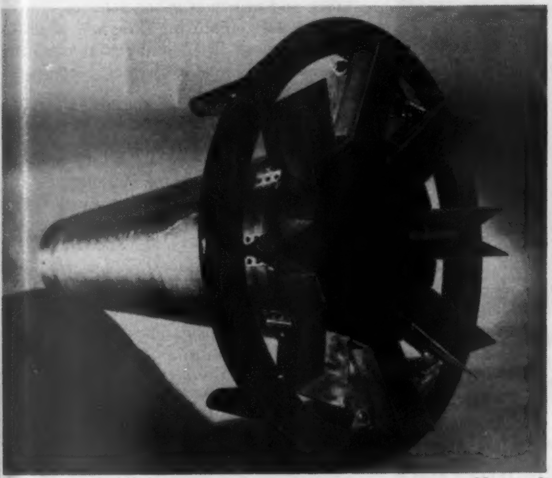
Date	Meeting, Place	Subjects	Chairman
Jan. 24	IAS Annual, N. Y. C.	(see p. 713)	
Mar. 14–16	ASME Aviation Conference, Los Angeles	High temperature	D. Shonerd, Aerophysics Development Corp., Box 949, Santa Monica, Cal.
June 17–21	ARS-ASME Semi-Annual Meeting, Cleveland	Liquid rockets, solid rockets, ramjets, satellites	H. C. Burlage, Case Inst. Technology, 10900 Euclid Ave., Cleveland 6, Ohio
Sept. 17–21	7th IAF Congress, Rome	Astronautics	
Sept. 24–26	ARS Fall Meeting, Buffalo	Propellants, combustion, telemetering	H. A. Ferullo, Bell Aircraft Corp., Buffalo 5, N. Y.
Nov. 25–30	ARS-ASME Annual Meeting, N.Y.C.		

Ramjets • • • •



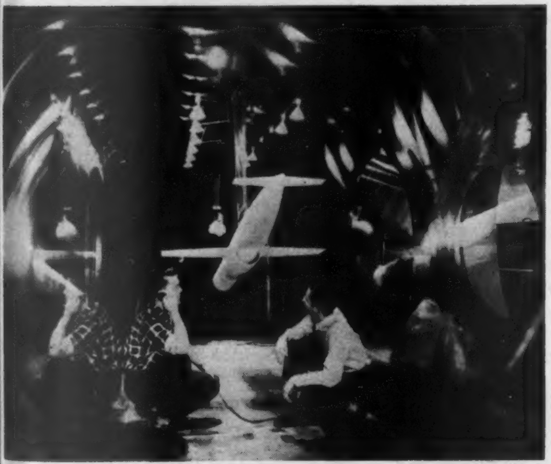
Ryan

Marquardt ramjet shown in cutaway



Marquardt

V-gutter type ramjet flameholder

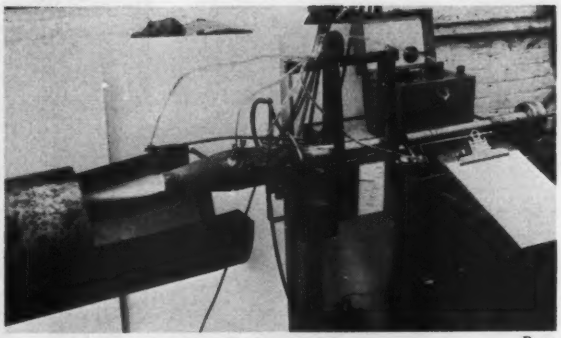


Ryan

NACA engineers set up ramjet model wind tunnel test

Ryan

First U. S. flight under ramjet power was made in F-80 carrying Marquardt ramjet engines at wingtips

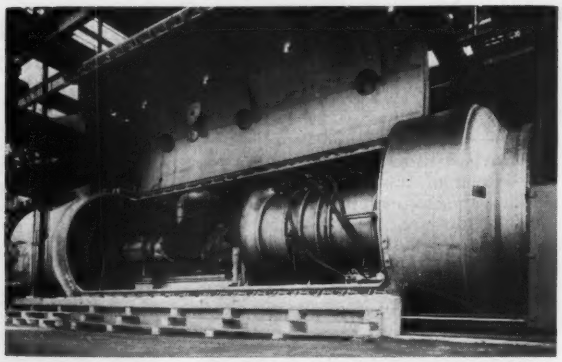


Ryan

Lab test of early ramjet model

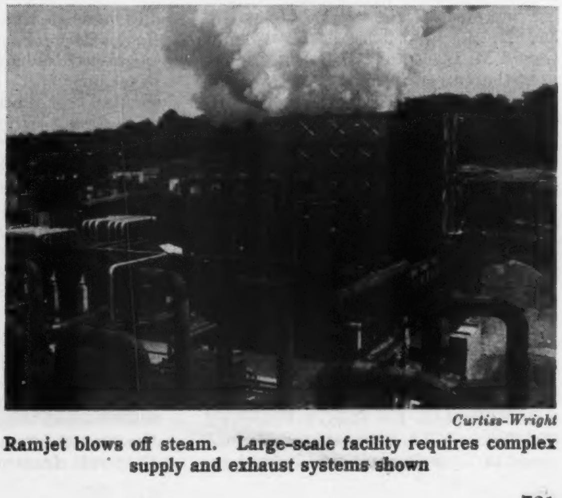
Univ. of Mich.

Static test of ceramic-liner ramjet



Curtiss-Wright

Giant ramjet test chamber is 98 ft long with 36-ft access hatch



Curtiss-Wright

Ramjet blows off steam. Large-scale facility requires complex supply and exhaust systems shown

ARS News

Harry F. Guggenheim (right) is awarded Honorary Membership by President Porter

Chicago Hosts 25th Anniversary Meeting

Davis elected president, Truax vice-president; Hoffman, Ritchey, Seifert, Stehling new directors

THIRTEEN technical sessions—one of which attracted an audience of more than 500—an Honors Night Dinner which saw fourteen distinguished people given awards, and an Annual Business Meeting at which the election of 1956 officers and new directors were announced, were the feature events of the 25th Anniversary Meeting at the Conrad Hilton Hotel in Chicago.

The meeting, held in conjunction with the Diamond Jubilee Annual Meeting of The American Society of Mechanical Engineers, was chairmanned by Kenneth H. Jacobs of the Chicago Section. On Jacobs' committee were Vincent J. Cushing, president of the Section, John Krc, Jr., D. J. Ljubenko, S. K. Coburn, Gerald M. Platz, and Ali Bulent Čambel.

At the Annual Business Meeting it was announced that Noah S. Davis had been elected president, Robert C. Truax vice-president, and the following as directors: For three-year terms—S. K. Hoffman, H. S. Seifert, and Kurt R. Stehling; for one-year term—H. W. Ritchey.

Two amendments to the by-laws were approved by an overwhelming majority of members. One calls for a rewording of the objectives of the Society. The other authorizes the Board of Directors to form divisions of ARS when appropriate.

The technical sessions are summarized on pages 732–736, except for the Space Flight Symposium and the Forum on Letter Symbols for Rocket Propulsion. The former will be covered in the January issue of Jet Propulsion. The latter session, which was conducted by ASA Subcommittee (Y-10), was presided over by Robertson Youngquist and J. P. Layton. It produced an effective exchange of views between audience members and Subcommittee members on the preliminary proposed symbols published in Jet Propulsion in November.

Reports from each of the ARS Sections were heard at a Section luncheon held on the second day of the meeting. A summary of these reports will be included in the January issue of Jet Propulsion.

Citations accompanying awards at the Honors Night Dinner

Honorary Membership to Harry F. Guggenheim: For his long and distinguished leadership and service in the development of the flight sciences, and since 1929 specifically in the development of rockets and jet propulsion; for first providing, along with his father, Daniel Guggenheim, substantial encouragement and support to the pioneer rocket researches of Robert H. Goddard, and later, through The Daniel and Florence Guggenheim Foundation, for continuing the support and interest which made possible the great accomplishments of Dr. Goddard in laying the foundations for today's growing field of rockets and jet propulsion; for bringing about the formation of two great centers of advanced rocket research, development, and education: The Daniel and Florence Guggenheim Jet Propulsion Centers at Princeton University and California Institute of Technology, and later still, by the development of the Institute of Flight Structures at Columbia University.

Astronautics Award to Wernher von Braun: For his part in the development of the first great engineering stride toward space, the V-2 Rocket; for his detailed analysis of the technical and logistic requirements for manned flight to other worlds; for his unremitting efforts to promote, both by public education and private persuasion, the cause of extraterrestrial flight; for his vision, his courage, and his single-minded advocacy of the feasibility and utility of space vehicles; for his enthusiasm, organizing skill, and engineering judgment in planning and executing concrete programs leading step by step in the direction of interplanetary travel.

Robert H. Goddard Memorial Award to Lt. Col. E. N. Hall, U.S.A.F.: For his vigorous advocacy of the utility of liquid propellant rocket power plants; for the skillful use of his broad technical knowledge to further the state of the art; for his keen foresight and sound management in devising and prosecuting programs for development of these engines.

C. N. Hickman Award to Fred S. Miller: For his unusual and important contributions to the solid propellant rocket effort; his ingenuity in research and development in an uncharted field, resulting in the discovery of the successful propellant combination which made the first Jato motor possible; his untiring efforts in the field of composite solid propellant rocket production, translating engineering prototypes into safely and efficiently mass-produced items of high reliability; his practical insight, sound judgment, and devotion to the solid propellant rocket program which have contributed so much toward advancing the art of solid propellant rocketry to large-scale production status.

G. Edward Pendray Award to Walter R. Dornberger: For his book "V-2," the most authoritative record of the history of the development of the V-2 Rocket; a highly readable account of the administrative and technical aspects of this monumental project.

James H. Wyld Memorial Award to Lt. Col. John P. Stapp, U.S.A.F.: For the application of rocket-propelled devices to the investigation of aeromedical problems; for his investigation of the effect of zero gravity conditions on animals through the use of Aerobee rockets; for his development of the rocket-propelled sled as a tool for investigating the physiological effects of high accelerations; for his personal courage in using himself as the experimental specimen.

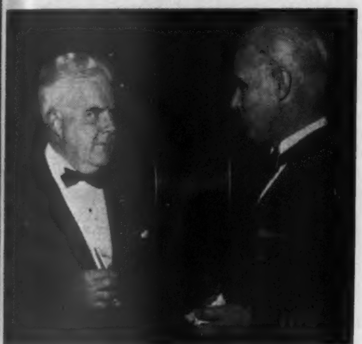
Student Award to Richard W. Foster: For the most meritorious paper submitted by a student member during 1955. The paper, entitled, "The Design, Construction, and Test Firing of the Purdue University Rocket Laboratory's Demonstration Rocket Test Stand," showed not only commendable insight into the principles of rocket test stand design, but an ability to present engineering facts in a clear and precise manner.

Rocket Men at Quarter-Century Milestone • • •

Exhibit of missiles, jet engines by General Electric

About 500 registered during the three-day meeting

Preprint table did heavy business all three days



Dr. Porter converses with Swedish air attache, Col. Stig Winnerstrom

Major D. G. Simons accepts Wyld Award from Mrs. James H. Wyld for Lt. Col. John P. Stapp

Mrs. Robert H. Goddard presents Goddard Award to Lt. Col. E. N. Hall

At Directors' Reception: Roy Healy, Kurt Berman, R. C. Truax, Lt. Col. E. N. Hall

Mr. and Mrs. Fred Miller chat with Chicago Section President and Mrs. V. J. Cushing

G. Edward Pendray gives Pendray Award to Kurt Stehling, accepting for Walter R. Dornberger

R. W. Foster accepts his second Student Award from Commander Truax

A. G. Haley, donor of Astronautics Award, presents it to Wernher von Braun

Fred Miller receives C. N. Hickman Award from Commander Truax

Guggenheim: "Mail Rockets in Five Years"

In receiving an Honorary Membership in ARS in recognition of his outstanding support of the rocket and jet propulsion field, Harry F. Guggenheim had some bold statements to make.

He said (1) that the use of rockets for carrying mail would be realized within five years, and (2) that ARS members could make today's jet transports as obsolete for intercontinental flight as the jet has made the piston-plane obsolete.

Mr. Guggenheim recalled his associations with the late Robert H. Goddard and gave the entire banquet audience souvenir photos of a 1941 Goddard rocket which anticipated the V-2 in several remarkable respects.

The complete speech follows:

This honor from your Society gives me mixed and paradoxical feelings, partly of pride and partly of humility.

My pride is in the knowledge that the honor comes to me through my association with two men—Dr. Goddard, the genius who fathered the art of jet and rocket propulsion, and my own father, who had the vision to sponsor this art. My humility is due to your willingness to accept me in your distinguished Society.

Goddard's historic paper published by the Smithsonian in 1920, "A Method of Reaching Extreme Altitudes," was a prime inspiration for this age of the rockets which we are just entering. My method for reaching the extreme altitude in which I find myself tonight is through the right combination of inheritance and environment.

This Society, I am informed, was started in 1930 by eleven men and one woman. They had great foresight and courage. It was in the same year that Dr. Goddard received his first grant from my father that initiated the research and rocket flights in Roswell, New Mexico. Your Society—I can now say our Society—has today a membership of nearly 4,000, and a very large part of this membership has been gained in recent years. So most of you can have little realization of how much vision and courage it took in 1930 for your twelve original members and my father to have devoted time, energy, and money in a field that the whole world considered visionary and futile.

I can best illustrate this point by telling you of Dr. Goddard's and my experience as late as 1941, when he was in the midst of rocket experimentation at Roswell, N. Mex., at the outbreak of World War II.

Bob Goddard called me on the telephone immediately after Pearl Harbor and asked, "What are we going to do now?" I told him that, if entirely agreeable to him, we should place all of our research, developments, patents, and organization at the disposal of the Government. He wholeheartedly agreed, and said that he would like to offer himself personally for Government service.

I arranged an appointment with the Chief of the Army Air Corps and the Chief of the Bureau of Aeronautics, in those days the heads of Army and Naval aviation, respectively. After a sympathetic reception, we were asked to present our project in detail to their representatives at a joint conference.

On hearing our story, the representative of the Army Air Corps, who was an Ordnance man, said, "all very interesting, but we don't think rockets will play any part in this war; we believe that this war is going to be fought with the trench mortar." The representative from Naval Aviation (I have a certain pride in feeling that Naval Aviation is exceptionally alert) said he thought there might be a specialized field in which Dr. Goddard's work would be useful, and that would be for jet-assist take-off. And throughout the war he was almost entirely restricted to the development of Jato for the Navy.

Periodically I would hear from or meet with Goddard and we would discuss means of getting the Armed Forces interested in rockets and plans for the future after peace. In December, 1944, a few months after the German V-2 began falling on London, Goddard visited me at Mercer Field, N. J., where I was at the time stationed as the commanding officer of a Naval Aircraft Facility. He brought along and gave me a photograph of one of his pioneering liquid fuel rockets taken in the Spring of 1941, and pointed out to me the points in common with the German V-2. I was so startled by the similarity that I turned the photograph over and asked him to put a brief inscription on its back. He wrote:

> "Rocket produced in New Mexico in the spring of 1941, under the Daniel and Florence Guggenheim Foundation.
> "It is practically identical with the German V-2 rocket."

I have before me a facsimile of the photograph. The rocket had the following features in common with the later German V-2's, among other things: (1) a similar arrangement of propellant tanks, (2) a general similarity of shape and placement of major parts, (3) liquid oxygen and alcohol as propellants, (4) gyro-stabilization and gyro-control, (5) steering by means of fins placed in the motor jet, plus steering by means of movable vanes in the airstream, (6) pumps to drive the propellants into the motor.

I thought you might all like to have as a souvenir a facsimile of this photograph, sufficient copies of which have been made for you. Incidentally, this rocket—in fact all of the later Goddard rockets—were affectionately known as "Nell" by the Goddard staff. After one of the early attempts at flight, when the rocket failed miserably, one of the staff shook his head sadly and said, "They ain't done right by our Nell." After that the rockets were all Nell.

During the experimental period in New Mexico, we envisaged three stages for the development of the art of rocket flight. The three stages were: first, to carry instruments to extremely high altitude for scientific research; second, to deliver mail and cargo at very high speed at great distance; and third, to transport passengers.

In this short time of fifteen years, the first step has already been accomplished. The second step can be taken, I dare say, in another five years time, and the third step will follow very shortly after that. You members of this Society have it in your hands to make the new jet planes to be delivered in 1960 as obsolete for certain aspects of intercontinental flight as the jet has made the piston engine obsolete.

The new jet planes with speeds of five to six hundred miles per hour must compete with rockets flying at three thousand miles or over per hour. The cost of operation and construction of jet planes for mail and special cargo will be prohibitive compared to that of the rocket. Why, for example, pay for the cost of fuel for transporting each pound of mail by airplane a distance of 5000 miles when by rocket you only have to pay for the cost of fuel for a distance of, say, 90 miles—60 up to altitude and maybe 30 more decelerating on the way down? For the rest of the five thousand miles, you can coast along in the ionosphere without fuel. As for construction and depreciation, the cost of a mail-carrying rocket should be only a fractional part of that of the modern jet passenger carrier.

I must warn you that in the past forty years my prophesies in various fields of the aeronautical sciences have been very wide of the mark—they have usually been gross understatements, in spite of the fact that at the time I was branded a partisan and a visionary.

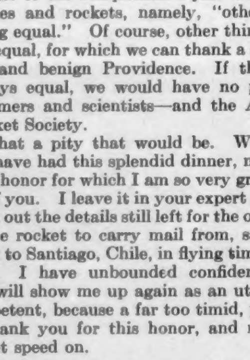
For example, in an address before the New York Railroad Club in December of 1927, at a time when there were no passenger air flights in the United States, I asked the question: "Will the systematic movement of goods and people by air play an important part in this generation in which we are living?" I then proceeded to analyze various factors of speed, safety, and cost in an attempt to give a positive answer to that question

And among other things, I said: "Although it seems fantastic to us to conceive of traveling commercially at a speed of 300 miles per hour today—nevertheless, the history of the past and especially the history of aviation, are evidence that the fantastic of today becomes the commonplace of tomorrow."

In deference to my new membership in this scientific body, I am going to add one phrase to the comparison I just made of jet planes and rockets, namely, "other things being equal." Of course, other things never are equal, for which we can thank a stimulating and benign Providence. If they were always equal, we would have no place for dreamers and scientists—and the American Rocket Society.

What a pity that would be. We should not have had this splendid dinner, nor I this high honor for which I am so very grateful to all of you. I leave it in your expert hands to work out the details still left for the operation of the rocket to carry mail from, say, New York to Santiago, Chile, in flying time of one hour. I have unbounded confidence that you will show me up again as an utterly incompetent, because a far too timid, prophet.

Thank you for this honor, and may the rocket speed on.



Kaplan: IGY has big Plans for "LPR"

The instrumented satellites to be launched during the International Geophysical Year 1957–1958 have an official nickname now—"LPR," or Long Playing Rocket. The dis-

closure came during the major address before the 25th Anniversary Honors Night Dinner by Joseph H. Kaplan, chairman of the U. S. National Committee for IGY.

Dr. Kaplan also announced the appointment of ARS President Richard W. Porter—toastmaster for the evening—as chairman of the Committee's Earth Satellite technical panel.

Dr. Kaplan said that the U. S. "will fire hundreds of research vehicles, ranging from the relatively small balloon or aircraft-launched vehicles, through multiple-stage, solid-propellant combinations to high performance Aerobees capable of reaching 200 miles." They will be launched from locations ranging from the Arctic to the Antarctic.

He said that about 10 LPR's would be fired, with the expectation that at least five would establish themselves in orbits, circulating at 200–800 mile altitudes for about two weeks.

The complete text of his address follows:

When one reviews the progress that has been made by man in his knowledge of the earth's atmosphere and its many complex and practically significant phenomena, and when one considers the related and concurrent progress in our knowledge of the sun and the rest of the solar system, it is no wonder that the proposed development of a scientific satellite for use during the International Geophysical Year has excited the imaginations and speculations of more people than perhaps any other scientific program in history.

From spectroscopic and radar observations of the aurora; from many-sided studies of the feeble atmospheric radiation known as the airglow; from meteor observations and experiments on sound and radio propagation at various levels of the high atmosphere, it has been possible to draw conclusions about the structure, composition and electrical properties of these regions, and even about the unusually complex motions in the very high atmosphere.

More than that, much of our present knowledge of the sun has been gained through these inferences, because the sun through its varying and complicated radiations, controls much of the structure and many of the processes of the atmosphere.

Man's curiosity, however, is never satisfied. Indirect observations of the aurora, made from the ground and in limited geographical areas, cosmic rays observed even with the best of our high altitude balloons, leave much yet to be observed and learned. The adaptation, about ten years ago, of rockets to the study of the earth's high atmospheer confirmed many of the things previously learned by indirect methods, but improved techniques and theories rapidly brought the rocket into its own as a research vehicle, and has provided information not accessible even to the large variety of indirect methods that now exist.

Based on our never-ceasing efforts to extend our frontiers, and based on the remarkable achievements of what we may soon refer to as conventional rockets, plans for launching instrumented satellites for geophysical research are now well under way, as part of the National Academy of Sciences' program for the International Geophysical Year. First, however, I want to tell you something about the conventional rocket program during the IGY, and then discuss the development of the satellite program.

The Rocket Program

The United States will fire hundreds of research vehicles during the IGY, ranging from the relatively small balloon or aircraft-launched vehicles through multiple-stage, solid-propellant combinations to high performance Aerobees capable of reaching 200 miles. These will be fired from locations that range from the Arctic to the Antarctic. Other countries will also contribute to the

rocket sounding field during the IGY, thereby extending the geographical coverage.

As I stated earlier, the scientific basis for the proposed rocket IGY program is to be found in the need for basic data which ground-based experiments are unable to provide. Lacking these data, for example, most existing theories on the cause and formation of the aurora, or the changes and fluctuations of the earth's magnetic field are very incomplete. Even in the case of the ionosphere there is as yet no completely satisfactory theory.

It is thought that the aurora is caused by charged particles from the sun. But no one has been successful in formulating a theory which simultaneously explains how particles are ejected from the sun, pass through interplanetary space, enter the atmosphere through the earth's magnetic field, and give rise within the atmosphere to the aurora. In fact, some point out that one does not yet know the true nature of the auroral phenomenon within the atmosphere so that lengthy discussions of extraterrestrial mechanisms for generating the aurora may be premature.

The relative roles of solar ultraviolet light, solar x-rays, and incoming particle radiations in the formation of the ionosphere are yet to be determined. There is, in fact, still considerable question as to the proper interpretation to be put on ground-based measures of ionospheric quantities.

In the field of solar-terrestrial relationships, the rocket alone can supply many of the needed answers. The character of the solar radiation at the bottom of the atmosphere is already considerably affected by the absorption of the high energy photons in the exosphere, the ionosphere, and the ozone layer. Ground-based measurements, for example, cannot indicate which solar radiations are responsible for producing the different ionospheric layers. The speculations as to solar flare radiations causing sudden ionospheric disturbances fill many volumes; the answer may be furnished during one rocket flight. Indeed, the entire problem of determining an adequate solar index for such effects as solar-weather relationships, sudden ionospheric disturbances, geomagnetic disturbances, and cosmic radiation increases, seems almost totally dependent upon measurements made from rockets.

The relations between the aurora, ionospheric currents, high altitude winds, and observed fluctuations in the earth's magnetic field are still to be clarified.

For a full understanding of the energy balance and general dynamic conditions within the high atmosphere, one must know at what levels, in what quantities, and in what spectral regions energy is absorbed or radiated. The relation of high altitude phenomena and conditions to low altitude meteorology is still an open question.

These examples indicate but a few of the many and complex problems in the high atmosphere awaiting solution. A fundamental purpose of the rocket IGY program is to shed further light upon such questions as these. To this end, experiments will be performed in the following disciplines:

1 *Atmospheric Structure.* Basic upper atmosphere meteorological data will be obtained at new locations and at various times by the employment of established rocket techniques. The quantities measured will be pressure, temperature, density, and winds.

2 *Atmospheric Composition.* The chemical and ionic composition of the high atmosphere will be determined by spectrographic and mass spectrometric methods. Special emphasis will be placed on the nature of the ions at the various ionospheric levels, since this is vital to further development of ionospheric theory. The vertical distribution of ozone, and the question of the pressure of nitric oxide and water vapor in the high atmosphere will also receive attention. Much of this work will be done within the auroral zone where our knowledge of the high atmosphere is meager.

3 *Radiation Studies.* There will be measurements of auroral Lyman-alpha and air fluorescence, determination of the heights and intensities of dayglow radiations. Rocket spectrograms will be made of the solar ultraviolet spectrum to wavelengths shorter than the Lyman-beta line of hydrogen. The solar spectrum in the ultraviolet and x-ray regions will also be studied by means of photon counters, with special attention to its behavior during solar flares.

4 *Particle Studies.* The nature and intensities of auroral particles, and the directional characteristics of auroral particle streams will be studied. Low energy cosmic rays will be measured as a function of geomagnetic latitude, and an effort will be made to correlate fluctuations in cosmic ray intensity with solar and magnetic phenomena.

5 *Ionospheric and Geomagnetic Measurements.* The variation of charge density with altitude in the ionosphere will be determined in the auroral zone by a variety of techniques. An effort will be made to distinguish between electrons and ions. Measurements will be made of the earth's magnetic field at various latitudes to provide information on the position and magnitude of electrical currents flowing in the lower ionosphere and on auroral particle streams.

Rockets make possible direct measurements of quantities which are either not observable or are only indirectly observable from the ground. They can also be used for measuring the altitude dependence of geophysical parameters. But they have a marked disadvantage in that they spend only a short time at any one altitude during their flight, and that their total flight time in itself is extremely short. Thus, particularly in the case of the large rockets used for extreme altitude studies, they are not easily adapted to synoptic type or long term studies. This is an unfortunate shortcoming, since fluctuations in such solar effects as ultraviolet and x-ray radiations, cosmic ray intensities, current rings encircling the earth, and particle streams impinging upon the high atmosphere are among the most important and interesting problems connected with the physics of the upper atmosphere and with solar terrestrial relationships.

The Satellite Program

An earth-circling satellite vehicle would, however, make it possible to make long term observations of quantities such as those listed above. Such a satellite could also be used as a means for refining geodetic data. The basic techniques for the launching and instrumentation of an artificial earth satellite are now available, and it is planned to launch a number of such vehicles as part of the U. S. IGY rocket program.

The satellite vehicle will orbit above the earth at altitudes between 200 miles at perigee, and perhaps 800 miles at apogee. In encircling the earth it will be observable by many countries and from many of the IGY stations being established for the over-all IGY program. In order to realize the greatest possible benefit from this undertaking, complete information about the orbiting vehicle and its instrumentation will be made available to the nations participating in the IGY program so that these countries can take part in the observation and make use of it.

It is planned to use the IGY satellite for the following types of experiments. The total number of experiments actually to be carried out will, however, depend on the total payload capacity of the vehicles launched.

1 Determination of outer atmosphere densities by observation of the air drag effect upon the satellite's orbit.

2 Obtaining of more accurate measures of the earth's equatorial radius and oblateness, of intercontinental distances, and of other geodetic data than are presently available.

3 Long term observations of solar ultraviolet radiation.

4 Studies of intensities and fluctuations in intensity of the cosmic and other particle radiation impinging upon the atmosphere.

5 Determination of the density of hydrogen atoms and ions in interplanetary space.

6 Observations of the Störmer current ring.

7 If possible, determination of the distribution of mass in the earth's crust along the orbital track.

With accurate determination of the orbit, the satellite can be used as the moon is used for geodetic measurements. Observations made of the artificial moon at different spots on the earth, either simultaneously or at precisely related times, can be used to determine the distance on the ground between observing sites. Also, by measuring the effect of the earth's oblateness on a satellite orbit moving in an inclined path relative to the equator, it should be possible to determine the actual amount of bulging at the equator. It may be, too, that nonuniformity in the distribution of mass in the earth's crust will cause an observable perturbation in the orbit, but in any case the effect will be much smaller than that caused by the earth's oblateness.

We have already outlined briefly some of the possible satellite experiments which can be performed with known rocket techniques. Because of experience in conventional rockets with the instruments required, one can feel confident of being able to design for any one of the studies mentioned a complete installation weighing between, say, 25 and 50 pounds and capable of fitting into the restricted space afforded by a small satellite vehicle.

Along with the instruments for measuring the parameter under study, such a complete instrumentation would contain such things as a telemetering transmitter, equipment for detecting the satellite's orientation in space, a control receiver and timing mechanism for turning equipment on and off, and an energy supply.

Cosmic rays could be studied in a satellite with Geiger counters, as they have been in ballistic and conventional rockets. As is now known, cosmic rays are composed of very high energy charged particles, roughly 80% protons, 18 or 19% alpha particles, the remainder being heavier nuclei. Being charged, the cosmic ray particles which attempt to move across the lines of force of the earth's magnetic field are deflected, and those of too low an energy do not reach the earth at all. Thus, cosmic rays experience a maximum deflecting effect at the equator where the magnetic field lines are horizontal and a decreasing effect with increasing geomagnetic latitude. Were it not for the atmosphere, the very lowest energy particle would penetrate to the earth's surface at the geomagnetic poles. It is, however, necessary to be above the atmosphere to observe the low energy particles. Thus, a satellite vehicle which moves in a polar orbit at 200 or 300 miles altitude would permit observations of the very lowest energy rays. The approach to continuous observations would permit study of fluctuations in cosmic ray intensity which have been noted in conjunction with magnetic and solar activity. Being above the atmosphere will be of considerable advantage here, since these effects are often most prominent in the low energy end of the spectrum. In the polar orbit, the magnetic field effect would help the observer

to sort out the rays into different energy groups, as is done in ballistic and conventional rocket experiments by making observations at different geomagnetic latitudes. The polar orbit however, would make the layout of ground stations extremely difficult.

Involving the highest energy particles known, the study of cosmic rays is of great interest to the scientist. The mystery of their origin is yet to be solved, and is felt to be linked with some of the most fundamental aspects of physics and the universe. From a practical point of view, cosmic rays interest the promoters of space flight, for they constitute a potential hazard.

As the source of most of the energy affecting the earth and its atmosphere, sunlight is of prime interest and importance. The ultraviolet and x-ray regions are absorbed at high altitudes causing photochemical activity, the ionosphere, heating, and winds. Variations in intensity of the solar radiations are felt in corresponding variations of atmospheric and weather phenomena. During the IGY, sunspot activity will be increasing greatly and especially favorable conditions will exist for studying solar-terrestrial relationships.

With photon counters in a satellite vehicle, the ultraviolet regions of the solar spectrum can be monitored above the absorbing atmosphere. In particular, the opportunity will exist to observe the ultraviolet light curve of the sun during the occurrence of solar flares.

From a practical point of view, solar radiation studies would contribute to a better understanding of the ionosphere, and of weather and climate. The practical value of improved knowledge in these areas is obvious.

Interplanetary space is not a complete vacuum. Its actual density, however, is not definitely known, although for a long time now the figure of one atom per cc has been used. The data on which this estimate is based are meager, and to provide a better estimate, Friedman and co-workers at NRL have proposed a most fascinating satellite experiment. Their proposal is to observe the sun directly in the Lyman-alpha (1216Å) region by means of photon counters, and simultaneously to observe the Lyman-alpha radiation emanating from some direction other than that of the sun. By correlating the intensities observed directly from the sun with those observed off at an angle, it should be possible to estimate the average density in space of hydrogen atoms and ions. Also, marked variations above the general average observed might be attributed to solar proton streams.

Small meteorite particles, a few thousandths of an inch in diameter, are constantly impinging on the earth's atmosphere. Although they doubtless enter with great speeds, the impact with air molecules soon slows them down, and they then drift to the ground. Estimates as to the quantity reaching the earth's surface vary, some reaching as high as 1000 tons per day for the whole earth. These meteorites are believed to contribute a small amount to the E-region ionization. They may some day concern the designer of space stations and space vehicles. With the use of simple impact detectors and electrostatic analyzers, these meteorites can be observed. In the impact detectors, resistance plates, or scintillation counters with photocells, can be used.

These are but a few of the experiments which would be performed in the early satellite vehicles using techniques already available. The sort of experiment considered, which is simple and conservative of weight, and which does not require visionary engineering and operational feats for its accomplishment, is the type which will be considered for the first satellite project. Tele-

vision, telescopes, radio relays, photography, and in fact anything requiring recovery of equipment or material from the vehicle, are definitely for the future. The first three items will require too much payload weight for the complicated equipment and large amount of energy needed, to be attempted in the early experiments. Photographs of the earth would involve the extremely difficult problem of getting the satellite back to earth safely and then finding it to recover the film.

However, here I should like to add a word of caution. The conservative satellite program we are planning is in itself a formidable technical task. To speculate even as I have done on more ambitious research programs can only be done if we understand that progress will be slow and difficult. Theoretically speaking, it is easy to conjure up all sorts of valuable experiments; practically speaking, one must face up to the difficulties.

Development of the Satellite Program

The interest of the U. S. National Committee for the International Geophysical Year in earth-circling satellite vehicles began with the adoption of resolutions during the summer and early fall of 1954 regarding the desirability of such vehicles. The resolution of most immediate interest to us is the one adopted on October 4, 1954, by the Special Committee for the IGY (CSAGI) of the International Council of Scientific Unions:

"In view of the great importance of observations during extended periods of time of extraterrestrial radiations and geophysical phenomena in the upper atmosphere, and in view of the advanced state of present rocket techniques, CSAGI recommends that thought be given to the launching of small satellite vehicles, to their scientific instrumentation, and to the new problems associated with satellite experiments, such as power supply, telemetering, and orientation of the vehicle."

In view of these international recommendations, and in view of the advanced state of U. S. rocketry developments, the Executive Committee of the U. S. National Committee for the IGY considered the possibility of constructing, launching, and observing an instrumented satellite. A special group was established for this purpose, composed of various members of the USNC Executive Committee and the USNC Technical Panel on Rocketry. I have already indicated how our satellite program was and is an extension of the rocket program. It may interest you to know that on the very first occasion when we considered the scientific merits and technical possibilities of the program, I coined the expression "LPR"—Long Playing Rocket—for the satellite effort, and we have used this designation in our deliberations ever since.

On the basis of recommendations made by our special study group, the Executive Committee decided that an instrumented satellite program was of scientific importance and feasible and it adopted a resolution which reads in part as follows:

"The Executive Committee of the USNC-IGY feels that a small artificial satellite for geophysical purposes is feasible during the International Geophysical Year if action is initiated promptly, and that the realization of such a satellite would give promise of yielding original results of geophysical interest."

The Executive Committee authorized the Chairman of the U. S. National Committee to transmit the above findings and resolution to the President of the National Academy of Sciences and the Director of the National Science Foundation. This was done on March 14, 1955.

The Executive Committee of the USNC-IGY proposed a minimum satellite program during the IGY, consisting of approximately

ten instrumented birds, with the expectation that at least five of the birds will be successfully launched into their orbits, circulating about the earth for a period of about two weeks, at heights of about 200 to 800 miles.

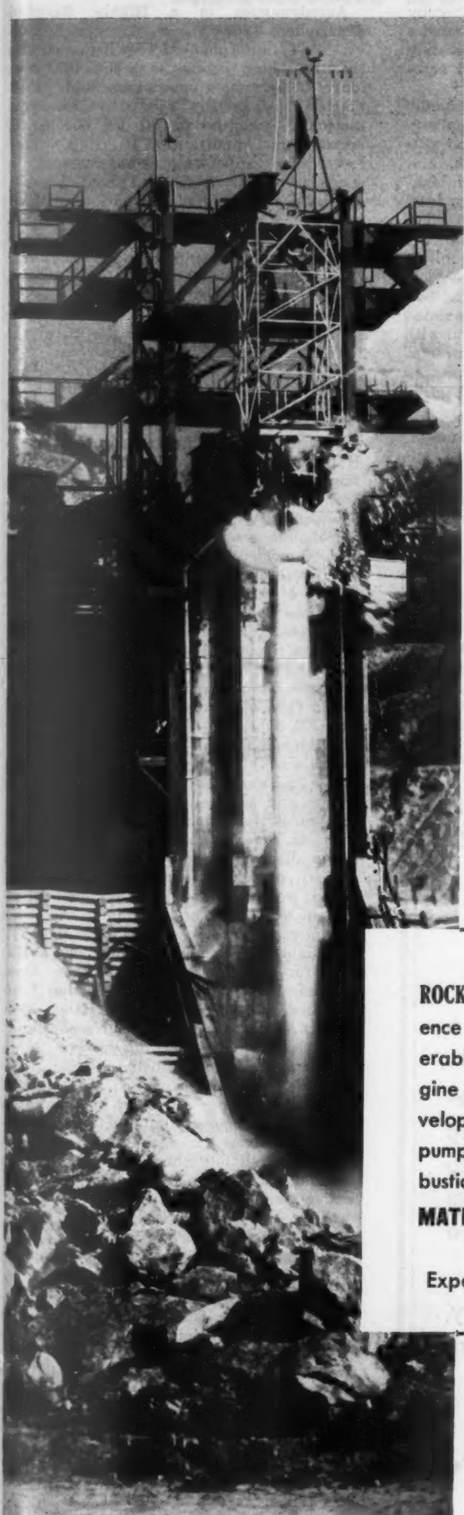
To achieve the objectives of the scientific program, the USNC Executive Committee outlined certain responsibilities. Clearly, the satellite program initiated by the USNC was to continue as an integral part of the USNC-IGY program with its execution under the direction of the USNC and its appropriate committees and panels, features that characterize all IGY programs. It was determined that the USNC-IGY budget should include the procurement of instrumented birds, the procurement of the rocket vehicle systems, ground stations, their scientific instrumentation and immediately associated supplies, and provisions for the employment of scientists; and that the USNC-IGY LPR budget be presented to the Government and Congress by the Academy under the auspices of the National Science Foundation. For obvious practical reasons, the Committee decided that the U. S. Government, through the Department of Defense and under the scientific direction of the USNC should provide logistics support as follows: scientific and technical personnel for vehicles, launching and instrumentation of vehicles and birds; all technical and field facilities, including laboratories, related structures, and quarters for personnel; and other types of logistic and operational support. Finally, the Committee declared that the cooperation of all scientists be invited with respect to the instrumented bird and the observation program, including provisions for participation in the observation at our field stations as well as issuance of data permitting ease of observation from other than our field stations.

The announcement by the White House on July 29, 1955, of the plans for the construction of an earth satellite vehicle is now a well-known fact in the history of this project. It occurred simultaneously with a similar announcement by Professor Sydney Chapman, President of the CSAGI, made in the Brussels headquarters of the CSAGI. The background of this announcement was contained in a letter dated July 26, 1955, from the chairman of the USNC-IGY to Professor Chapman, which was graciously acknowledged by him in a letter dated August 3, 1955.

The reception by scientists of the forty or more other nations which will participate in the IGY of the news of the proposed U. S. satellite was a warm one indeed. This reception was based in part on the great admiration by scientists of other countries for the past achievements of American rocket scientists. In part, too, this reception was based on the knowledge that the value of the observations made during the IGY would be enhanced greatly by the availability of the direct data obtainable only by rockets and satellites.

What can be said of the value of these efforts? My own evaluations go along the following two general lines: First, that the IGY rocket and satellite programs will provide invaluable knowledge of several kinds. There will be the direct data which will greatly enhance the ground-made observations and which may lead to major breakthroughs in our theories and understanding of atmospheric phenomena. There may also be specific new and major discoveries of terrestrial and interstellar events with these tools that reach beyond the earth's heavy atmosphere.

Second, the satellite program in particular will represent the first step in man's exploration of the universe beyond the earth's immediate atmosphere. Here I am thinking solely in terms of a practical progression that



may reasonably be expected in the years ahead as heavier payloads become possible. These will permit the conduct of vastly more ambitious and potentially more rewarding experiments.

These prospects are by their very nature provocative and challenging and they have these characteristics because we are here dealing with an endeavor close to the spirit of man: his eternal quest for knowledge and the truth about the universe in which he finds himself.

Technical Papers Presented at the ARS 25th Anniversary Annual Meeting

AERODYNAMICS

Hypersonic Studies of the Leading Edge Effect on the Flow over a Flat Plate (268-55). A. G. Hammitt and S. M. Bogdonoff, Forrestal Research Center, Princeton University. A study of flow about the leading edge of a flat plate and the experimental equipment used for the study. This flow involves several hypersonic fluid dynamics problems. At hypersonic speeds most shocks are strong and the entropy changes through the shock cannot be neglected. Reflected waves and viscous forces are important. The study of the problem was carried out in a hypersonic wind tunnel using helium as the working fluid.

The Aerothermodynamic Problems of Hypersonic Flight (269-55). A. Hertzberg, Cornell Aeronautical Laboratory, Inc. Measurements carried out immediately behind a strong shock are presented, showing the variations of the properties of air at high temperatures. Techniques of hypersonic flow generation in the laboratory which simulate flight conditions are introduced. Modified versions of the shock tube are presented. Techniques are given whereby aerodynamic parameters (e.g., heat transfer rates), may be measured. The application of the shock tube to materials and aerostructural testing is outlined.

Hypersonic Flight: Some Aerodynamic Considerations (270-55). J. S. Isenberg, Bell Aircraft Corp. Magnitudes and distributions of the forces, heat loads, and temperatures acting on a body in ultrahigh-speed flight (i.e., speeds and altitudes from 1000 to 30,000 fps, and sea level to 500 miles, respectively) are considered. Then the principal aerodynamic features and problems of each of the three classes of hypersonic vehicles—lifting or cruising aircraft, ballistic missiles, and satellites—are pointed out. Basic flow phenomena associated with hypersonic flight are discussed as well as current ability to predict qualitative and quantitative effect.

Aerodynamics in a Highly Rarefied Atmosphere (267-55). S. A. Schaaf, University of California. At very high altitudes the atmosphere becomes so rarefied that it no longer behaves as a continuous fluid. Phenomena, such as "slip" related to the discrete molecular structure of the air become of aerodynamic importance. Utilizing a very low-density supersonic wind tunnel, a series of aerodynamic and heat transfer studies have been made for various geometrically shaped models of aerodynamic interest such as cones, cylinders, flat plates, and spheres. These results are presented and discussed. It is shown that, in general, pressure forces and equilibrium temperatures are higher because of these effects, while skin friction and heat transfer rates are lower.

COMBUSTION

Flame Stabilization in High Speed Streams (271-55). J. J. Zelinski, R. E. Walker, and P. Rosen, Applied Physics Lab., The Johns Hopkins University. Quantitive information obtained shows the dependence of mass flow into the recirculation zone upon pressure, flow velocity past the flameholder, and flameholder size. Empirical equations are derived which match the experimental stability limits of flameholders to the limit curve of the spherical reactor. These equations show the relationship of equivalence ratio at blowout to airflow rate, static pressure, flameholder geometry, and velocity past the flameholder.

Flame Stabilization Resulting from Cyclonic Flow of Mixtures of Natural Gas and Air (273-55). Lyle F. Albright, University of Oklahoma, and Lloyd G. Alexander, Carbide and Carbon Chemicals Co. Highly stable flame can be obtained when mixtures of air and natural gas flow cyclonically. Apparatus tested include emergent cyclonic free jets, straight and bent ducts about 0.5 in. in diam and 4 to 20 in. long, and a conical diverging section. Flames produced were stabilized at superficial velocities up to 700 fps, and in many cases the rate of energy release seemed to be high.

Reliability of Combustion Efficiency Evaluation for Jet Propulsion Based upon Aerodynamic Measurement of Combustion Temperature (272-55). Gilbert S. Bahn, Marquardt Aircraft Co. Main source of random error is evaluation of nozzle exit Mach number. Resulting probable errors in combustion efficiency, expressed as either a temperature rise or a ratio of fuel/air ratios to compare theoretical and actual performances, is about ± 5 per cent. This is reasonable reliability and less doubtful than off-hand estimates made to provide conservative views.

CONTROL SYSTEMS

Transistor Reliability (275-55). Donald E. Barnes, Bureau of Ships, U. S. Navy. An estimate of the relative position of transistor reliability, and a brief review of the history of the subject. The problem is approached through selected answers to two questions—(1) Has transistor reliability improved? (2) Can reliable transistorized equipment be designed now? The answers selected are in three categories; namely, the reliability required, the nature of transistor failure, and system design.

HIGH ALTITUDE RESEARCH

Sun Follower for High Altitude Sounding Rockets (266-55). D. D. Terwilliger and G. J. Granos, Aircraft Armaments, Inc. One phase of upper atmosphere research is the direct measurement and absorption of solar radiation. Aircraft Armaments, Inc., was associated with the NAL program in building units which house the spectro-

Greetings from Sweden

ARS was honored at the 25th Anniversary Meeting by the Royal Swedish Air Board, Propulsion Department, Guided Missile Section.

Col. Stig Winnerstrom, air attache of the Swedish Embassy (photo, p. 723) presented a Swedish flag and mast mounted on a plaque to President Porter. A plaque on which a guided missile was engraved was presented by Dr. Porter to Col. Winnerstrom for transmittal to the Royal Swedish Air Board.

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Aerodynamics

__267-55 Aerodynamics in a Highly Rarefied Atmosphere, S. A. Schaaf, University of California.

__268-55 Hypersonic Studies of the Leading Edge Effect on the Flow Over a Flat Plate, A. G. Hammitt and S. M. Bogdonoff, Forrestal Research Center, Princeton University

__269-55 The Aerothermodynamic Problems of Hypersonic Flight, A. Hertzberg, Cornell Aeronautical Laboratory, Inc.

__270-55 Hypersonic Flight: Some Aerodynamic Considerations, J. S. Isenberg, Bell Aircraft Corp.

Combustion

__271-55 Flame Stabilization in High Speed Streams, J. J. Zelinski, R. E. Walker, and P. Rosen, Applied Physics Lab., The Johns Hopkins University

__272-55 Reliability of Combustion Efficiency Evaluation for Jet Propulsion Based upon Aerodynamic Measurement of Combustion Temperature, Gilbert S. Bahn, Marquardt Aircraft Co.

__273-55 Flame Stabilization Resulting from Cyclonic Flow of Mixtures of Natural Gas and Air, Lyle F. Albright, University of Oklahoma, and Lloyd G. Alexander, Carbide and Carbon Chemicals

Control Systems

__248-55 Automatic Production of Electronic Equipment, Clay Lafferty, Armour Research Foundation

__249-55 Selectivity through Mechanical Resonance, Roy Olsen, Motorola, Inc.

__275-55 Transistor Reliability, Donald E. Barnes, Bureau of Ships, U. S. Navy

High Altitude Research

__264-55 Applications of the Satellite Vehicle, R. P. Haviland, General Electric Company

__265-55 Transfer Between Circular Orbits, Derek F. Lawden, College of Technology, Birmingham, England

__266-55 Sun Follower for High Altitude Sounding Rockets, D. D. Terwilliger and G. J. Granos, Aircraft Armaments, Inc.

__274-55 Preliminary Study of a Satellite Station Concept, Darrell C. Romick, Goodyear Aircraft Corp.

Instrumentation

__245-55 The Turbojet Exhauster Story, T. E. Hudson, Marquardt Aircraft Co.

__246-55 The Solution of Two-Dimensional Steady State Heat Transfer Problems by the Use of Electrically Conductive Paper, Leo E. Dean, Bell Aircraft Corp.

__247-55 Launching and Handling of Large Liquid Fueled Guided Missiles, T. M. Pettey, Jr., General Electric Company

__250-55 Statistical Evolution of Istrumentation for Rocket Engine Testing, J. M. Zimmerman, North American Aviation, Inc.

Liquid Propellants

__236-55 Test Methods for Monopropellants, P. F. Winternitz, N. Y. University

__237-55 Storability of Nitric Acid, D. M. Mason, Jet Propulsion Lab., California Institute of Technology

__239-55 Rocket Performance Measurements with Streak Photographs, M. F. Heidmann and C. M. Auble, Lewis Flight Propulsion Lab.

__240-55 Optimum Ratio of Propellants for a Liquid Bipropellant Rocket Operating Within a Mixture Ratio Tolerance, J. A. Broussear, Jr., Boeing Airplane Co.

Materials and Design

__261-55 Special Ceramic Materials of Construction for Rocketry, H. M. Killmar and W. L. Wroten, The Carborundum Co.

__262-55 Fiberglas-Reinforced Plastic as a Rocket Structural Material, S. M. Breslau and K. D. Miller, The M. W. Kellogg Co.

__263-55 Evaluation of Some New Materials for Missile and Powerplant Applications, A. V. Levy, Marquardt Aircraft Co.

Rocket Systems Stability

__238-55 On the Dynamic Stability of Rocket Power Plants with Liquid Propellants, Rudolph H. Reichel, Bell Aircraft Corporation

__254-55 On the Stability of Flame Fronts in the Combustion of Liquid Fuel Droplets, C. C. Miesse, Aerojet-General Corporation

Solid Propellants

__257-55 Some Effects of the Weapons System Concept on Rocket Engine Design, H. M. Kindsvater and I. H. Culver, Lockheed Aircraft Corp.

__258-55 The Use of Weapons Systems Engineering Concepts in the Design of Solid Propellant Missile Power Plants, H. L. Thackwell, Jr., Grand Central Rocket Co.

__259-55 A Quasi-Morphological Approach to the Geometry of Charges for Solid Propellant Rockets, Jack M. Vogel, The Ramo-Wooldridge Corp.

__260-55 Observations on the Irregular Reaction of Solid Propellant Charges, Leon Green, Jr., Aerojet-General Corp.

Space Medicine

__241-55 Climatization of Animal Capsules During Upper Stratosphere Balloon Flights, Major D. G. Simons, Aeromedical Field Lab., Holloman Air Development Center

__242-55 The Medical Problems Involved in a Manned Artificial Satellite, Hubertus Strughold, USAF School of Aviation Medicine, Randolph Field.

Space Flight Symposium
The Unmanned Satellite

__276-55 Lifetimes of Satellites from Near-Circular and Elliptical Orbits, N. V. Peterson, Sperry Gyroscope Co.

__277-55 Basic Aspects of Space Law: (1) The Unmanned Earth Satellite, Andrew G. Haley

__278-55 Applications and Design Characteristics of Minimum Satellites, S. F. Singer, University of Maryland

__279-55 Control and Power Supply Problems for the Unmanned Satellite, Ernst Stuhlinger, Redstone Arsenal

__280-55 The Recovery of a Satellite Vehicle, Kurt R. Stehling, Bell Aircraft Corporation

__281-55 Instrumenting Unmanned Satellites, Herman E. LaGow, Rocket Sonde Branch, Naval Research Laboratory

__282-55 Satellite Ascent Mechanism, J. Jensen, Glenn L. Martin Company

Thermodynamics and Heat Transfer

__243-55 The Vortex Tube as a True Free Air Thermometer, Jack C. Hedge, Armour Research Foundation

__244-55 High Capacity Turbojet-Powered Heat Exchanger, J. H. Schmidt, Marquardt Aircraft Co.

__255-45 Heat Transfer and Fluid Friction Characteristics of White and Red Fuming Nitric Acid, H. Wolf, F. L. Gray, and B. A. Reese, Purdue University

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New York University

graph and direct solar radiation to the spectrograph. To obtain sufficient exposure times at the shorter wavelengths, the spectrograph is kept pointed at the sun, regardless of rocket spin and precession. This is accomplished by a Sun Follower, design and performance of which are described.

Applications of the Satellite Vehicle (264-55). R. P. Haviland, General Electric Co. Fields where the satellite vehicle has potential usefulness include: mapping and cartography, communications, weather charting and forecasting, research, and development of space flight. These fields fall into groups which look "inward" from the satellite, toward the earth, and those which look "outward," away from the earth. This paper is an introduction to the possibilities and problems of the inward looking fields, and is a review paper, since none of the basic ideas is new.

Preliminary Study of a Satellite Station Concept (274-55). Darrell C. Romick, Goodyear Aircraft Corp. Engineering analysis of an associated manned satellite station concept utilizing the final stage of a 3-stage ferry rocket as the basic building block for the station. This concept also provides a station which starts affording its function of crew protection and accomodation from the beginning.

INSTRUMENTATION

The Turbojet Exhauster Story (245-55). T. E. Hudson, Marquardt Aircraft Co. Design and operation of an unusual exhauster installation used for altitude testing of ramjet engines. The installation consists of four J-33 turbojet engines modified so that they may be driven by the exhaust gases from two J-47 turbojet engines. The turbojet engines used as exhausters may be operated either in parallel or in series. In series operation, test cell pressures as low as 1.5 psia are easily attained.

The Solution of Two-Dimensional Steady State Heat Transfer Problems by the Use of Electrically Conductive Paper (246-55). Leo E. Dean, Bell Aircraft Corp. An electrical analogy test program developed to assist in solving heat transfer problems involving irregularly shaped boundaries. Test technique consists of applying a voltage to sheets of electrically conducting teledeltos paper shaped to similate design configuration to be investigated.

Statistical Evolution of Instrumentation for Rocket Engine Testing (250-55). J. M. Zimmerman, North American Aviation, Inc. The program for measurement analysis presented demonstrates the use of statistical techniques and design of analytical experiments. Based on these results, the many sources of measurement inaccuracy are evaluated, and a comprehensive corrective and control program is described. Extensive use is made of examples from a rocket research program.

Launching and Handling of Large Liquid Fueled Guided Missiles (247-55). T. M. Pettey, Jr., General Electric Co. Discussion is limited to missiles with pumped propellant feed systems, as they present a greater variety of interesting problems. Missiles involved were 30 ft long and 3 ft in diameter, their weights varying from 4 to 6 tons. From earliest preliminary design of a missile system, launching and handling must be factored into all parts of the system.

LIQUID PROPELLANTS

Test Methods for Monopropellants (236-55). P. F. Winternitz, N. Y. University. Short history of Committee on Monopropellant Test Methods. Scope of the Committee is outlined, and principal characteristics to be determined are listed, including available chemical energy, rate of energy conversion, efficiency of conversion, initiation of decomposition relative to performance and handling, combustion properties, and limitations imposed by physical state.

Rocket Performance Measurements with Streak Photographs (239-55). M. F. Heidmann and C. M. Auble, Lewis Flight Propulsion Lab. Streak photographs were used to measure the axial gas velocity of combustion gas flow within a rocket engine. Experimental tests made with a 200-lb thrust engine using several injectors and chamber lengths, show that gas flow is readily displayed by the techniques employed.


Douglas
announces...
the formation of a separate
Missiles Engineering Department
Corporal
Bumper Wac
Sparrow
Roc 00-1000
Wac B
Nike
Roc xx
Aerobee
Honest John
Growing importance of missiles in the nation's defense has led to the separation of missiles engineering from aircraft engineering functions at Douglas Aircraft Company.
Leadership in this important field has been won by Douglas in 14 years of development and design of guided missiles for the Armed Forces. Douglas is currently engaged in eight major missiles projects, under contracts from the Air Force, Army and Navy.
Formation of the new department at Douglas opens new opportunities for engineers and scientists interested in the missiles field. Write to: E. C. Kaliher, Engineering Personnel Manager, Missiles, Douglas Aircraft Co., Santa Monica, California.
Missiles by DOUGLAS
First in Aviation

Optimum Ratio of Propellants for a Liquid Bipropellant Rocket Operating Within a Mixture Ratio Tolerance (240-55). J. A. Brousseau, Jr., Boeing Airplane Co. For systems designed for propellant exhaustion, close control of the burning mixture ratio and weight ratio of loaded propellants must be maintained, if sizable quantities of unburned propellant are to be avoided at shutdown. Consideration is given to the problem of unburned propellant resulting from a bipropellant rocket operating over a range of mixture ratios. Equations are derived from a mathematical analysis which provides tools for optimizing the weight ratio of propellants for any given operating mixture ratio tolerance.

Properties of Fuming Nitric Acid Affecting its Storage and Use as a Rocket Propellant (237-55), by David M. Mason, Jet Propulsion Laboratory, California Institute of Technology. Some of the general problems of storing fuming nitric acid (the system HNO_3–NO_2–H_2O) in closed metal containers for periods of the order of months at elevated temperatures around 130 F are discussed. A literature review of some of the physicochemical properties of importance for satisfactory storage and use as a rocket propellant, as well as a discussion of chemical methods of analysis, is included.

MATERIALS AND DESIGN

Fiberglas-Reinforced Plastic as a Rocket Structural Material (262-55). S. M. Breslau and K. D. Miller, The M. W. Kellogg Co. These plastics offer an opportunity to make design improvements in weight, cost, and precision. Weight reduction is achievable only if the nature of the material is carefully taken into account, and a satisfactory balance is achieved between conflicting variables.

Special Ceramic Materials of Construction for Rocketry (261-55). H. M. Killmar and W. L. Wroten, The Carborundum Co. Early in the development of uncooled rocket motors it became obvious that metal nozzles were inadequate. Seeking a better material, many products including various ceramic bodies were considered and evaluated. Accumulated design information can be used to advantage in extending use of ceramic materials as replacements for high-temperature metal alloys.

Evaluation of Some New Materials for Missile and Powerplant Applications (263-55), by A. V. Levy, Marquardt Aircraft Company. Reviews performance, properties, fabrication of high temperature materials—reinforced plastics, HK31 thorium, zirconium magnesium, refractory coatings, titanium alloys, molybdenum alloys.

ROCKET SYSTEMS STABILITY

On the Dynamic Stability of Rocket Powerplants With Liquid Propellants (238-55), by Rudolf H. Reichel, Bell Aircraft Corporation. Contrary to present theoretical publications in the field of liquid propellant engines, taking only the low and high frequency combustion stabilities into consideration, the treatment of the power plant stability is here considered from a practical point of view according to design and control mechanism.

Depending upon the specific purpose, a rocket propulsion system may consist of different processes alone or in combination with control loops. Interaction of the components would result in a multiloop control system. The influences which determine the stability are treated in a general manner, and corresponding examples are presented. Moreover, the special importance of engine component characteristics with respect to the dynamic stability is exhibited. A proposal is made to investigate rocket power plants by a servo-analyzer similar to that applied for industrial purposes.

On the Stability of Flame Fronts in the Combustion of Liquid Fuel Droplets (254-55), by C. C. Miesse, Aerojet-General Corp. Summary unavailable.

SOLID PROPELLANTS

Some Effects of the Weapons System Concept on Rocket Engine Design (257-55). H. M. Kindsvater and I. H. Culver, Lockheed Aircraft Corp. Studies have shown how good engine design can result in increased missile performance. However, performance improvements gained in one component of the missile can readily be lost in another subsystem unless the total system concept is applied to all components. This emphasizes the need to evaluate the requirements of the vehicle as a complete weapon in an operational environment.

A Quasi-Morphological Approach to the Geometry of Charges for Solid-Propellant Rockets (259-55). Jack M. Vogel, The Ramo-Wooldridge Corp. A morphological classification of charge designs is developed based upon their several distinguishing characteristics. Using the morphological classification as a datum, a quasi-morphological approach seems to be well adapted to the field of charge design. A family tree inter-relating charge configurations can be established by inventing or identifying a means of compensating for some undesirable feature of a chosen design, extending the principle or inverting the principle.

The Use of Weapons Systems Engineering Concepts in the Design of Solid Propellant Missile Power Plants (258-55). H. L. Thackwell, Jr., Grand Central Rocket Co. When designing a solid propellant missile, important principles to keep in mind are: (1) The lowest weight motor is not necessarily the best for the job. (2) During missile preliminary design stages, motor specifications should be kept flexible. (3) Close coordination should be maintained with the propellant manufacturers so that necessary compromises can be made in time. (4) Avoid, if possible, use of an existing powerplant which was (or is) being developed for another purpose.

Observations on the Irregular Reaction of Solid Propellant Charges (260-55). Leon Green, Jr., Aerojet-General Corp. A review of development experience and research studies emphasizes a difference in usage of the equivocal term "unstable burning" by the rocket designer on the one hand and the theoretical investigator on the other. Evidence indicates that high-frequency pressure oscillations of finite amplitude can prevail in the charge cavity during outwardly "stable" operation. A possible coupling mechanism by which gas-phase oscillations may effect exaggerated rates of solid-phase decomposition is suggested.

THERMODYNAMICS AND HEAT TRANSFER

High Capacity Turbojet-Powered Heat Exchanger (244-55). J. H. Schmidt, Marquardt Aircraft Co. The heat exchanger installation described handles the large quantities of air (100 to 700 lb per sec) consumed in testing ramjets. In these tests, the required heat input reaches 300 million Btu per hr, and the exchanger goes through abrupt temperature cycling, perhaps as many as six times a day or 1000 cycles per year.

Heat Transfer and Fluid Friction Characteristics of White and Red Fuming Nitric Acid (255-55). H. Wolf, F. L. Gray, and B. A. Reese, Purdue University. Results of an experimental investigation to determine the convective heat transfer and fluid characteristics of red (RFNA) and white (WFNA) fuming nitric acid. Tests were made under conditions simulating the regenerative cooling of a rocket motor—that is, in forced convection in horizontal tubes.

The Vortex Tube as a True Free Air Thermometer (243-55). Jack C. Hedge, Armor Research Foundation. A vortex tube was designed and tested which measures true temperature to an accuracy of within ±1 deg F or better for the Mach number range 0.2 to 1.0. It indicates little sensitivity due to altitude changes, at least up to 38,000 ft, and appears insensitive to changes in ambient temperature for the range from −50 deg F to +60 deg F.

Mehagen Describes J-65

SPEAKER at the September 28 meeting of the **Chicago** Section was Mr. Mehagen, Asst. Supt. of Engine Testing, Jet Engine Plant, Buick Motor Div., Willow Springs. He described the fabrication and testing of the J-65 turbojet engine. The meeting was held at Armour Research Foundation's Technology Center.

The October 26 meeting featured an inspection tour of the Nike site at Skokie, where demonstrations included handling, storage, firing facilities, and a simulated firing. The military installed outdoor lights for the occasion.

Classified Discussion on Missiles

A CLASSIFIED discussion of Nike missile and power plant was the feature of the October 27th meeting of the **Southern California** Section. Panel experts participating in the discussion, held at the plant of Aerojet-General Corp., Azusa, were: J. L. Bromberg, R. B. Canright, E. R. Elko, J. R. Piselli, and A. L. Walton. Registration was limited to the first 250 applications received from paid-up members, and clearances for Confidential (or above) were required from the Security Officer, Office of Naval Research, Pasadena. Nominations for directors and officers of the Section were presented by the nominating committee.

Talk on Upper Atmosphere Studies

TALBOTT CHUBB of the Optics Division, Naval Research Laboratory, gave a talk on ultraviolet and x-ray measurements in the upper atmosphere at the October 6 meeting of the **New Mexico-West Texas** Section. He described the construction of photon counters used in upper atmosphere studies, and the means by which the counters are made to discriminate frequencies. Counters are used to investigate various layers of the atmosphere, and to determine effects caused by radiation from different layers of the sun's atmosphere. Dr. Chubb also discussed plans for studies of this type to be conducted during the International Geophysical Year.

Chicago Section president V. J. Cushing (third from left) presents charter to Fort Wayne Section president N. L. Baker. Looking on are M. Katanik (left) and M. Stults, Section officers

Fort Wayne Section Receives Charter

AT A dinner meeting on August 9 at the YMCA, **Fort Wayne** became the twenty-second section to receive an ARS charter (photo). After the charter presentation, Vincent J. Cushing, president of the Chicago Section, gave a talk on "Frontiers of Space," followed by a movie "X Minus Zero."

Another meeting was held on September 20 at Indiana Technical College, where, after a short business session, a lecture was given by Section president Norman L. Baker on "High Altitude Cosmic Ray Studies," based on data obtained during August by the Air Force Medical team from Holloman AFB in Minnesota.

Members and their guests were accorded a tour of a Nike missile site at River Rouge Park, Detroit, on September 24. After the briefing and tour, dinner was served in the modern mess hall.

Conference on Satellite Design

FIRST program of the **Detroit** Section's Fall season was held October 7 in the Engineering Society auditorium, Detroit. S. Fred Singer, guest speaker, discussed the general design of the MOUSE satellite. Alfred J. Zaehringer, Art Nichols, and Al Weir discussed rocketry and space flight, on radio station WWJ, and Dr. Singer and Fred Klemach appeared on a WWJ-TV telecast. A press conference held for Dr. Singer at the Park Sheldon Hotel was attended by representatives of newspapers, TV stations, and the Armed Forces.

Space Travel Discussion at Syracuse

KURT STEHLING of Bell Aircraft gave an illustrated talk on the immediate prospects for space travel, at the October 21 organizational meeting of a proposed **Central New York** Section. The meeting was held at Maxwell Auditorium, Syracuse University. Information on activities of the new Section may be obtained from Rolland R. Schreib, Jr., Syracuse University, Syracuse 10, N. Y.

Maryland Meeting Attended by 200

MORE than 200 members and their friends attended the September 27 meeting of the **Maryland** Section held at Johns Hopkins University. Frank M. Perkins, chief of the Operations Analysis group, Convair (San Diego), presented a paper on the flight mechanics of ascending satellite vehicles. Before the meeting, officers met for dinner to discuss future plans and business of the Section.

Field Trip to Steel Plant

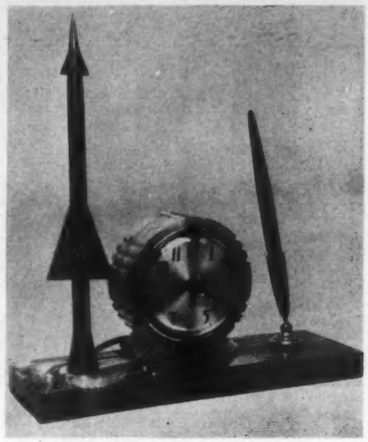
DICK STEWART is given much credit for the successful and spectacular field trip arranged for the **Southern Ohio** Section on October 20. Despite hurried last-minute arrangements, forty members made the field trip to the plant of Armco Steel Co.

Dallas-Fort Worth Section Planned

A PETITION for a charter for a section in the **Dallas-Fort Worth** area was submitted to the national organization of the ARS, following an organizational meeting of representatives from four aircraft companies. Approximately 30 area engineers comprise the charter membership. Geo. H. Craig (Convair) was elected temporary president; Harry Graham (Chance Vought) chairman of membership committee; Barry Acord (Bell) by-laws committee; Bob Jones (Temco) chairman of election Committee; and Jim Nolan (Convair) program chairman.

New York Section Visits Forrestal Research Center

ON October 1 the **Princeton Group** of the **New York** Section was host to that Section. The group guided more than 200 members and guests around the James Forrestal Research Center, Princeton. On display were various subsonic and supersonic laboratories. Visitors also saw two rocket firings and a jet mixing study. After lunch, members attended the football game and saw the local team beat Columbia 20 to 7.



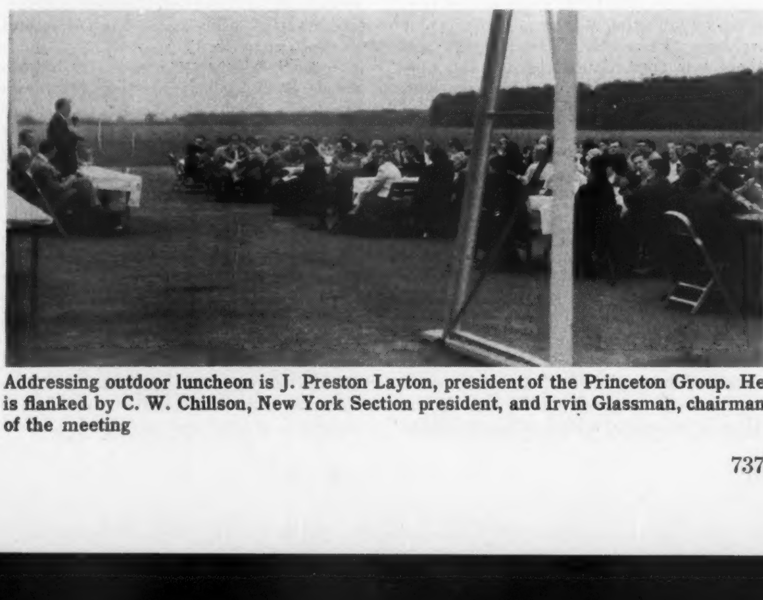
Annual Bendix Prize Paper Award

MEMBERS of the **Southern Ohio** Section may compete for a new trophy donated by the Hamilton Division, Bendix Aviation Corp. The contest is for the best technical paper of less than 4000 words on some topic relating to jets and rockets. The prize is an electric desk clock with a pen set on one side and a model rocket on the other (photo). The name of the winner will be inscribed on a metal plate on a green onyx base.

Conditions of the award, and a list of suggested topics, may be obtained by contacting the Chairman of the Paper Award Committee, John T. Marshall, Chief Engineer, Bendix Aviation Corp., Hamilton, Ohio.

Combined Meeting by ARS and AWA

THE **National Capital** Section held its most successful meeting of the year at the National Aviation Club in Washington, D. C., October 6. Homer Newell, Jr., of the NRL, briefed on forthcoming artificial satellites. Door prizes were given by Bell Aircraft, Convair, Capital Airlines, and *Aero Digest*. The October 31 meeting was a joint venture with the Aviation Writers Association, when a panel of five experts answered questions from the press regarding artificial satellites.



Addressing outdoor luncheon is J. Preston Layton, president of the Princeton Group. He is flanked by C. W. Chillson, New York Section president, and Irvin Glassman, chairman of the meeting

ABC Foto, Copenhagen

Opening assembly at the IAF Congress

Pressehuset, Copenhagen

K. F. Ogorodnikov, L. I. Sedov, and F. C. Durant, III

Impressions of the Sixth Astronautics Congress

Frederick C. Durant, III

Arthur D. Little, Inc., Cambridge, Mass.

TWO important events spotlighted the Sixth Congress of the International Astronautical Federation (IAF) at Copenhagen, Denmark, August 2–6, 1955. Delegates of rocket and astronautical societies of eighteen countries were already on their way to Copenhagen when news of the first event broke—the White House announcement of a satellite vehicle project as part of the U. S. program for the International Geophysical Year. This news was not only startling in itself but had some far-reaching implications. The other event was the attendance of an IAF Congress for the first time by the Russians. Leonid I. Sedov and Kyrill F. Ogorodnikov were no ordinary observers but top scientists sent by the USSR Academy of Sciences. Professor Sedov, author of several textbooks on aerodynamics and mechanics, was named some months ago as President of the Academy Commission on Interplanetary Sciences. Professor Ogorodnikov is an astronomer at the University of Leningrad.

For the average engineer or scientist active in responsible rocket and astronautical societies, the U. S. program was in a sense a vindication of their past efforts and writings. Particularly at Copenhagen there was good-natured banter and universal tales of associates and superiors who for years had cast sidelong glances or made fun of them as Buck Rogers'. More soberly it was recognized that the announcement of the program was a historic event—a breakthrough in astronautics, a significant spurt in the advancement of science and technology.

The White House press release stated clearly that the satellite vehicle program would be based on security classified guided missile developments and that full details of the system logistics, etc., therefore could not be released. However, full details of the satellite itself and anticipated orbits would be made public in sufficient time for interested scientists to participate in the observation program. After all, this is the only information of real pertinence and interest to scientists. The altitude, mass, volume, configuration, attitude, instrumentation (if any), time, velocity, and direction of flight of the satellite at burnout are all important. The technique and details of placing the satellite in orbit are strictly incidental.

As a first item of business at the Congress, a resolution was introduced by the Swiss delegation and adopted unanimously to send a congratulatory message to President Eisenhower and to express the desire of the IAF to assist in the program in any appropriate manner. It was suggested that the Federation's official publication, *Astronautica Acta*, might be useful in disseminating information as released. This year-old Journal published by Springer-Verlag of Vienna has already established itself in international scientific circles. A White House reply to this cablegram, signed by Sherman Adams, was received the following day stating that President Eisenhower "particularly appreciated your readiness to assist in this project and has requested the American scientific authorities directly concerned to give careful study to your offer."

The arrival of the team of Russian observers at the business meeting of the Congress was greeted with spontaneous approval by all delegates. First of all, this was the first recognition and support of the IAF by a national government, all member societies being nonprofit, professional organizations. More than this, though, had been the concern of Federation members that the organization was becoming politically oriented to the west. For an international organization based upon science and technology alone, a political orientation, albeit undesired, could seriously hamper membership growth and professional value. Speaking for the Russian team, Sedov stated that he was present to observe and carry back a report to the Academy of Sciences. Presumably this report would be studied to examine the possibilities of affiliation with the Federation. Sedov and Ogorodnikov attended all social functions which were part of the Congress activities. They mingled freely with the delegates and were accepted on common grounds of interest. Since Sedov spoke German and Ogorodnikov English there was not much language difficulty, and by the end of the week the Russians departed leaving an excellent impression of friendliness. Apart from an irresponsible misquote by one wire service that "the Russians would launch a larger satellite vehicle in eighteen months," which was contradicted the following day, the press dealt quite fairly with the Russians. It was appreciated generally by the journalists that it was a rare opportunity to talk directly with these men. In the main, Sedov and Ogorodnikov stressed the desire for "cooperative rather than competitive" spirit in astronautics.

Other items of business at the Congress included a study of discussions with UNESCO and a possible program of IAF affiliation. Under the chairmanship of Andrew G. Haley, past-president of the ARS, a suggested program will be drawn up by an international committee during the coming year for review by UNESCO. Delegates heard of the initiation of interest and steps toward organization of new rocket and astronautical societies in France, Belgium, Japan, Italy, Mexico, and Peru. An extensive film show of U. S. rockets, guided missiles, and Bell Aircraft X-series aircraft shared plaudits with the recent Walt Disney film, "Man in Space."

The Constitution of the IAF was amended to permit membership of nonprofit institutions and organizations as Affiliate Members. The application of The University of Cuyo at Mendoza, Argentina, was accepted for this type of membership. The University of Cuyo for three years has had an Institute of Astronautics. Officers for 1955–1956 were elected as follows: President: F. C. Durant, III; vice-presidents: T. M. Tabanera of Argentina, and G. A. Crocco of Italy; secretary: J. A. Stemmer of Baden, Switzerland.

The date and place for the 1956 Congress were set for September 17–22 at Rome (with due regard for the summer heat of

Rome and the Farnborough Show!).

The following papers were presented during the technical sessions of the Congress:

Krafft Ehricke: The Satelloid.

H. H. Koelle: Vorschlag fuer ein realisierbares Raumfart-Programm der naechsten 30 Jahre.

A. Hitchcock: Some Considerations in Regard to the Physiology of Space Flight.

G. A. Partel: Some Problems on Rocket Development.

R. Penacchi: An Approximate Solution of the Motion Equation of a Rocket and Application to the Research of the Best Burning Time.

H. E. Newell: The Role of Rockets in the International Geophysical Year.

R. Tousey: The Visibility of an Earth Satellite.

S. F. Singer: Cosmic Ray Effects on Matter at High Altitudes.

Norman Petersen, F. I. Ordway, III: Estimated Lifetimes of Satellites.

A. Boni: Artificial Satellite Orbit Synchronizing System.

D. F. Lawden: Optimum Launching of a Rocket into an Orbit about the Earth.

J. M. J. Kooy: Calculation of the Powered Flight of a Long Range Rocket, Supervised by an Automatic Pilot.

Leo Hansen: Temperature Problems in Astronautics.

J. Eugster: Der heutigen Stand der biologischen Erforschung der Kosmischen Strahlung.

C. E. Cremona: Metoda Fotografico Per La Determinazione Della Resistenza Aerodinamica Di Missili in Volo.

B. Langenecker: Berich ueber Metallphysikalische Untersuchungen fuer Raketenantriebe.

D. C. Romick: A Suggested Organization of Space Flight Sciences.

Design Philosophy of the ARS Astronautics Award

F. J. Malina

Paris, France

Astronautics Award Trophy

THE award represented by a trophy and medal was endowed in 1954 by Andrew G. Haley, first chairman of the Space Flight Committee of the American Rocket Society, to be awarded annually for a period of 100 years. He specified that there should be place on the base of the trophy for the names of 100 recipients. The only other specification for the trophy was that it should be made of bronze.

I decided that the design of the trophy should meet the following conditions:

1 It should convey a feeling of space without being fragile.

2 It should contain no elements that would be likely to become invalid over a period of 100 years.

3 The names of the recipients should be inscribed on a base which was an integral part of the trophy design.

The trophy, as shown in the photograph, finally evolved. It contains the following symbolic aspects:

1 An ellipsoidal base cut on four sides to provide plane surfaces for inscribing the title of the award and the names of the recipients. Symbolically, the conquest of space rests upon the men whose names are inscribed on the base.

2 A sphere, symbolizing the earth, rests on a portion of its planetary orbit around the sun.

3 From the earth projects a portion of the path of a vehicle bound for interstellar space. The path passes through a pyramid of ellipses symbolic of the orbits of the planets around the sun. The path extends into space beyond the solar system. The pyramid also symbolizes the towers used in the launching of the first rockets for the study of the upper atmosphere such as used by Robert H. Goddard in his New Mexico tests and by myself for the WAC Corporal.

4 The elements of the bronze trophy are in the following colors: (*a*) The base and vehicle path in blue, symbolizing space. (*b*) The planetary orbits in gold, symbolizing their path around the sun. (*c*) The sphere in earth color.

Sidelights on the Design and Fabrication of the Trophy

1 After making preliminary sketches I constructed a crude full-scale model. For the earth I borrowed, after some argument, my 5-year-old son's rubber ball which happened to be of the correct diameter.

2 The element of the trophy most debated was the vehicle trajectory—whether it should be vertically straight or curved. I finally decided to have it slightly curved to give the trophy a greater dynamic feeling.

3 A scaled drawing was prepared and shown to Professor Dropsy of the Institut de Beaux Arts in Paris who recommended V. S. Canale as qualified to fabricate the trophy.

4 The atelier (workshop) of V. S. Canale is an old bronze-making establishment on the Quai d'Horloge on one of the islands in the Seine river. Due to the ill health of Monsieur Canale the fabrication of the trophy was supervised by the kind and charming Madame Canale. After parts of the trophy had been made, I was told the trophy was the most difficult piece they had ever made. It turned out that they had made the parts to an unnecessary degree of accuracy. They had not been presented with a detailed scale drawing of an art object before, but were in the habit of working roughly from a clay model.

ARS Astronautics Award Trophy

Astronautics Award Medal

It was specified that the medal be of the same dimensions as other medals of the American Rocket Society and that it was to be of gold.

I decided the design of the medal should meet the following conditions:

1 The design elements should be closely related to the elements of the trophy.

2 It should contain no elements that would likely become invalid over a period of 100 years.

The medal contains the following symbolic aspects:

Front: 1 The edge of the medal represents the orbit of the earth around the sun. A raised hemisphere symbolizes the earth on its oribit. 2 Circling the earth is shown the moon on its orbit. 3 The path of an earth-launched vehicle is shown pointing toward the stars at the upper part of the medal. 4 A sense of motion is imparted to the design by the bow- and arrow-like configuration of the trajectory intersecting the moon's orbit, and a sense of space by the hollowed-out central portion of the medal.

Reverse: The plaque on which the names of recipients are to be inscribed is surrounded by a field of interesting ellipses, the ancient fruitful symbol which today symbolizes planetary orbits or orbits of particles in the heart of the atom on whose energy the power for space flight may finally depend.

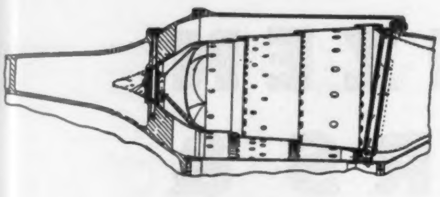
Sidelights on the Design and Fabrication of the Medal Dies

1 The drawing of the design was given to V. S. Canale to make dies for the medal. A plaster model, three times the size of the medal, was prepared, and from this model the dies were cut by a technique which is considered such an important trade secret that only members of the establishment are permitted to see it.

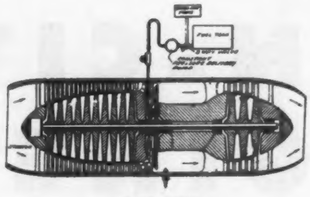
2 Three bronze copies of the medal were struck. They are in the possession of A. G. Haley, V. S. Canale, and myself.

New Patents

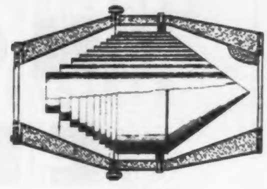
George F. McLaughlin, *Contributor*



2,720,080



2,720,750



2,720,935

Combustion equipment for gas turbine engines with means for supporting the flame tube from an air casing (2,720,080). George Oulianoff and Jeffrey Evans, Alvaston, England, assignors to Rolls-Royce, Ltd.

An inlet flame-tube section connecting inner and outer walls at their ends, adjacent to the inlet end of the air casing. The section overlaps struts having recesses adapted to receive the inlet flame-tube section, and aligned with the strut bores when the inlet is received in the recesses.

Method of maneuvering combination submarine and aircraft (2,720,367). Donald B. Doolittle, Wilmington, Del., assignor to All American Engineering Co.

Normally nonbuoyant craft capable of operating as a propeller-driven submarine and surface craft, and jet-propelled aircraft. Lifting forces raise the craft from below the water to the surface where the jet engine is cut in. A hydrodynamic lifting force raises the craft from the surface of the water, and it becomes airborne.

Turbojet engine control (2,720,752). Milton E. Chandler, New Britain, and Alexander M. Wright, West Hartford, Conn., assignors to Nils-Bement-Pond Co.

All-speed governor which varies its speed in accordance with ambient air density. It automatically varies fuel flow directly with air density at any position of the manual control lever. Constant, predetermined engine speed is obtained under variable operating conditions.

Fuel vaporizing combustion apparatus for turbojet (2,720,081). Herbert W. Tutherly, Media, Pa., assignor to the U. S. Navy.

Method of spraying fuel into the stream of primary air flowing into the inlet of a preheating duct. An auxiliary primary air passage in the hood structure effects confluence of the rich fuel and air mixture from the preheating duct with sufficient primary air to support combustion in the imperforate ignition portion of the shell.

Revolving fuel jet ignition systems for jet engines and gas turbines (2,720,750) Helmut R. Schelp, Patterson Field, Ohio, assignor to the U. S. Air Force.

Means for delivering liquid fuel to a relatively stationary conduit at constant pressure. Nozzles arranged on the rotor are of different lengths so as to inject fuel directly into the zones of compressed air which issue from concentric annular passages.

Fuel supply apparatus for resonant pulse-jet combustion device (2,717,637). Ludwig R. Haber, Uberlingen am Boden See, Germany, assignor to Swingfire (Bahamas) Ltd.

Valveless resonant exhaust pipe directly connected with the combustion chamber to form an acoustic resonator. Fuel supply apparatus consists of a venturi tube connected between the fuel condensation chamber and the combustion chamber.

Combustion apparatus (2,720,753). Alan Sharpe, Melbourne, Australia, assignor to Power Jets (Research and Development) Ltd.

Device for burning fuel droplets in a gas stream. Combustion chamber and ducts are so dimensioned that the flow path within the vaporizing duct outside the mixing duct has a flow area less than the transverse flow area of the mixing duct outlet.

Sound deadening means for jet engine test stands (2,720,276). Carl C. Droeger, Greenfield, Ind.

Test stand with passages filled with bundles of tubular conduits comprising an annular mass of sound-absorbent material. Internal and external sheathing is provided for each mass. Sheathing is a sheet of material having a cohesive strength greatly exceeding that of the sound absorbent material.

Flameholder for ramjet engine (2,720,754). Guy L. François, Ferguson, Mo., assignor to McDonnell Aircraft Corp.

Flameholders spaced from one another in a common plane within an elongated tubular member, for imposing a swirling action on the air-fuel mixture passing between the inner and outer flameholders.

Silencing of sound (2,720,935). Alf Lysholm, Gustav Karl WM. Boestad, and Hans R. Nilsson, Stockholm, Sweden, assignors to Jarvis C. Marble, New York, Leslie M. Merrill, Westfield, N. J., and Percy H. Batten, Racine, Wisc.

Pipe elements within a casing with radially spaced outer and inner walls, with sound-deadening material between the walls. The pipes, closed at one end, extend axially of the casing, and confront the perforated inner wall of the casing.

Jet-propelled aircraft with extendable intake channel (2,721,045). Willard R. Custer, Hagerstown, Md.

Jet tube extending longitudinally through the fuselage, and having a forwardly opening channel through the forward end. Channel may be moved for extension forwardly of the nose of the aircraft.

Propelling device (2,717,744). Arnold Birnbaum, Irvington, N. J., assignor to The M. W. Kellogg Co.

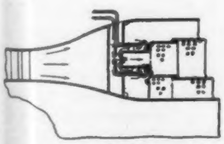
High velocity jet engine providing thrust to move a launching carriage mounted on a beam-like way. Guide means on the way form passages for reversing the flow of the exhaust from the jet, converting portions of the exhaust energy into additional thrust on the carriage.

Time delay nose fuze for a rocket (2,718,192). Charles F. Bowersett, Arlington, Va., and Wm. J. Donahue, Jr., and Kenneth L. Baker, Washington, D. C.

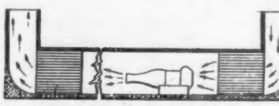
Device for maintaining an arming member locked in safe position and adapted to be moved slidably to release position when the inertial force caused by acceleration of the rocket has been decreased to a predetermined value.

Nozzle closure assembly (2,720,749). Murray C. Beebe, Jr., Palos Verdes Estates, Calif., assignor to Hughes Aircraft Co.

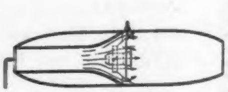
Reaction propulsion device with shear pins coupling an end portion of a nozzle closure. Pins are shearable in response to the force supplied to the closure member by the pressure produced by ignition of the combustible charge.



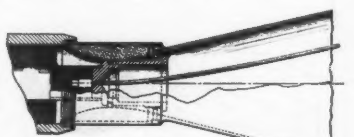
2,720,081



2,720,276



2,720,754



2,720,749

Editor's Note: The patents listed above were selected from recent issues of the Official Gazette of the U. S. Patent Office. Printed copies of patents may be obtained at a cost of 25 cents each, from the Commissioner of Patents, Washington 25, D. C.

Book Reviews

A. B. Čambel, Northwestern University, *Associate Editor*

Electrons, Atoms, Metals and Alloys, by William Hume-Rothery, revised printing, Philosophical Library, New York, 1955, 387 pp. $10.

Reviewed by T. J. Hughel
Purdue University

This is a revised printing of the work of the same title which first appeared in 1948. This book is almost unique in the field of metallurgical publications in that it is a popularization of the most fundamental concepts of modern physics as they apply to metals and alloys. Hume-Rothery seems to have the happy gift, which is often found in first-rate English scientists, of being able to reduce the most abstruse branches of modern science to a form which the intelligent layman can digest. While reading this book the reviewer was reminded of the popular works of such great British scientists as Jeans and Eddington.

Hume-Rothery has chosen to write this book in the form of a dialogue between an "Older Metallurgist" and a "Young Scientist." The Older Metallurgist is visualized as a man educated in metallurgy prior to 1920 who has had an outstanding career in the nonferrous foundry industry. The scientist is a physicist or physical chemist educated since the advent of quantum theory. The Young Scientist undertakes to instruct the Older Metallurgist in the newer theories of physics as they apply to metals using the tutorial style of teaching. Many readers, of whom this reviewer was one, may find the dialogue form of writing becoming tiresome long before the end of the book is reached, but the content of the book is more than sufficiently interesting to make up for the rather trying dialogue presentation.

The book is divided into four major sections: I—The nature of an atom; II—The nature of a metal; III—The nature of an alloy; IV—The structure of the nucleus. These four major divisions are further subdivided into a total of 45 chapters. The chapters are quite short, averaging about eight pages, so that the reader is not required to exercise a very long attention span in order to absorb the content of each chapter. The major part of the revision of the present printing was done in the chapters on plastic flow and those on nuclear physics. The author states in his preface that he considers both of these topics to be outside the main scope of his book and that he has made no attempt to bring the sections concerned completely up to date. This reviewer agrees that nuclear physics is outside the main scope of metallurgical science and might well have been given an even more abbreviated treatment in the present book than was done. However, plastic deformation, as treated by the newly developed theory of dislocations, is not only highly germane to metallurgy but represents one of the most important and exciting new developments in solid state physics. It might well have been treated more fully.

Dr. Hume-Rothery takes the occasion of his concluding chapter to make some remarks regarding metallurgical education which are certain to seem gratuitous to many readers. The Older Metallurgist asks the advice of the Young Scientist regarding the education of the older man's son for a career in metallurgy. The advice given is that the son should study physical chemistry and abjure all departments of metallurgy in the various universities. These metallurgy departments are accused of paying only lip service to science and of being primarily teachers of technology. Presumably this comment was meant to apply chiefly to British educational institutions, and no doubt this viewpoint had much justification prior to World War II to American as well as British schools. During the past ten years several American institutions and at least one in England—the University of Birmingham—have made great strides toward placing their metallurgy departments on a sound scientific basis. In the light of this fact, it seems to this reviewer that Hume-Rothery might well have toned down somewhat his remarks on metallurgical education in this revised printing of "Electrons, Atoms, Metals and Alloys." His failure to do so may well cause a bad aftertaste from what is otherwise quite a delightful book.

Thermodynamics and Physics of Matter, Vol. I of the Princeton Series on High Speed Aerodynamics and Jet Propulsion, Princeton University Press, 1955, 812 pp. $15.

Reviewed by S. S. Penner
California Institute of Technology

A book comprising 812 pages and containing well-written and authoritative reviews (on "Fundamentals of Thermodynamics" by Rossini; "Fundamental Physics of Gases" by Herzfeld, Griffing, Hirschfelder, et al.; "Thermodynamic Properties of Real Gases and Mixtures of Real Gases" by Beattie; "The Transport Properties of Gases and Gaseous Mixtures" by Hirschfelder, et al.; "Properties of Liquids and Liquid Solutions" by Richardson and Brinkley; "Critical Phenomena" by Rice; "Properties of Solids and Solid Solutions" by Ewald; "Relaxation Phenomena in Gases" by Herzfeld; "Gases at Low Densities" by Estermann; "The Thermodynamics of Irreversible Processes" by Curtiss) is worth buying even at $15 per copy. One can neither criticize the technical excellence of the material in this book nor the manner of presentation, particularly of those parts which are either lifted from other books with little change (e.g., by Rossini, Hirschfelder, et al., on "The Kinetic Theory of Gases," Beattie) or else represent condensation of material discussed elsewhere in greater detail (Hirschfelder, et al., on "Transport Properties).''

Perhaps a fair yardstick to adopt in the evaluation of this book is to consider to what extent the various topics are discussed in such a way as to serve the avowed purpose of the Princeton Series, namely, to provide an intelligible introduction to physical science for aerodynamicists and jet propulsion researchers who have not had extensive previous training in the physical sciences. From this point of view the book represents a very heterogeneous collection indeed.

The section on thermodynamics is detailed enough and sufficiently simple to provide an excellent survey for almost anyone wishing to study this subject.

The discussion of quantum mechanics, molecular structure, and bond energies in Section B is beautifully done but unfortunately altogether too brief to give the reader real insight into the vast area of physical science covered. The same remark applies to the survey of statistical thermodynamics. The discussion on the kinetic theory of gases (Chapter 7 of "Molecular Theory of Gases and Liquids" by Hirschfelder, et al.) should provide the serious student with strong motivation for purchasing the book for which this material was originally prepared.

By contrast, the discussion in Section C on the thermodynamic properties of real gases and gas mixtures is very detailed and complete. The limited audience interested in this material should find the treatment exhaustive. The survey of transport properties in the following section is commendably brief and written in such a way that many readers, who will not really understand the derivations and origin of the results, will nevertheless begin to comprehend what the final equations mean. The treatment of critical phenomena is again relatively detailed, more descriptive, and easier to follow.

The section on liquids and liquid solutions is too elegant to serve as an introduction to the theory of the liquid state for aerodynamicists. The topics on crystal properties and gases at low densities, and on the thermodynamics of irreversible processes, since they involve material for which the "typical" reader will be rather better prepared than for some of the earlier sections, should provide useful surveys if not useful introductions to these areas of science. Herzfeld's treatment on relaxation phenomena in gases represents an original evaluation of a subject which is of great current interest.

The fact that the book is a part of the Princeton Series on High Speed Aerodynamics should mean that it will provide a needed and beneficial, though perhaps too exacting, exposure to physics and chemistry for many engineers. It is to be hoped that the reader turning to this book for his first serious introduction to analytical science will take advantage of the bibliographies and will supplement, at least some of the briefer and more difficult sections, with outside material. With this reservation, the reviewer believes that the first volume of the Princeton Series may, in the words of Th. von Kármán, "have far-reaching beneficial effects on the further development of the aeronautical sciences."

Probability and Information Theory, with Application to Radar, by P. M. Woodward, McGraw-Hill Book Co., New York, 1953, 128 pp. $4.

Reviewed by J. J. MARTIN
Missile Division—Bendix Products

This applied mathematics book is one of a series of monographs in the Electronics and Waves Series. The particular field treated is the application of probability and information theory to the problems arising in the transmission and reception of radar signals. The careful reader will find information in the various sections leading to applications other than those mentioned specifically. The monograph, divided into seven chatpers of approximately 20 pages each, deals in turn with probability theory, waveform analysis and noise, information theory, statistical problem of reception, theory of radar reception, mathematical analysis of radar information, and the transmitted radar signal. For the most part, the book may be read casually by those desiring general information on the subject, or with intent by those wishing to apply the information immediately. In either case, the reader will find a less impersonal approach than is often found in American technical books.

The concise treatment of probability theory is in sufficient detail to answer the questions raised in later chapters of the text but is not in sufficient detail for those readers wishing to make an exhaustive study of the subject. The chapter on waveform analysis and noise is presented as general background and preparatory information for the succeeding chapters. The chapter on information theory is well written and presents material having application outside that specified by the author. For example, the guided missile designer can well make use of the information given in an effort to gain a more logical interpretation of telemetering data obtained with the superposition of noise.

The last four chapters deal with a variety of subjects all of which are important to designers of either the radar system itself or the control systems which are dependent upon the radar system. Generally speaking, the discussion is restricted to cases in which the noise is Gaussian and "white."

"Probability and Information Theory," as well as a very few other texts, is the beginning of a literature for the advanced engineer giving the analytical approach to the design of control systems and the systems feeding information into such control systems. The monograph presently under discussion is well written and is succinct and readable enough to deserve wide reading.

Book Notices

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Technical Literature Digest

M. H. Smith, *Associate Editor,* **and M. H. Fisher,** *Contributor*
The James Forrestal Research Center, Princeton University

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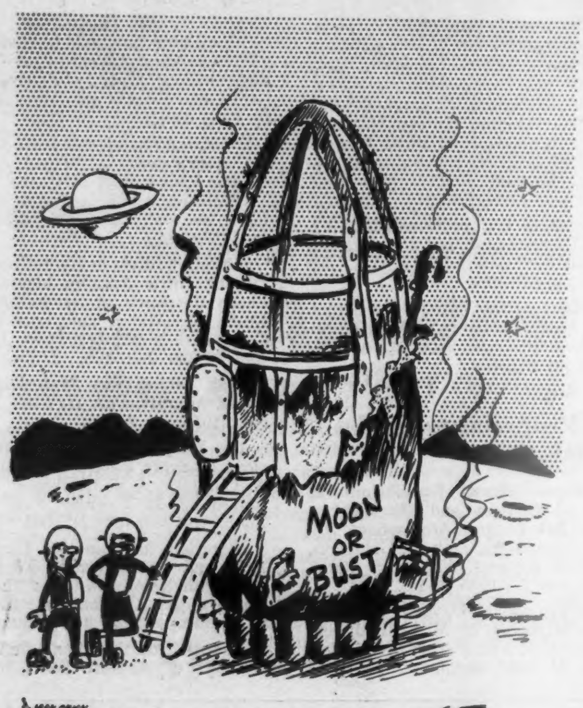
Editor's Note: This collection of references is not intended to be comprehensive, but is rather a selection of the most significant and stimulating papers which have come to the attention of the contributors. The readers will understand that a considerable body of literature is unavailable because of security restrictions. We invite contributions to this department of references which have not come to our attention, as well as comment on how the department may better serve its function of providing leads to the jet propulsion applications of many diverse fields of knowledge.



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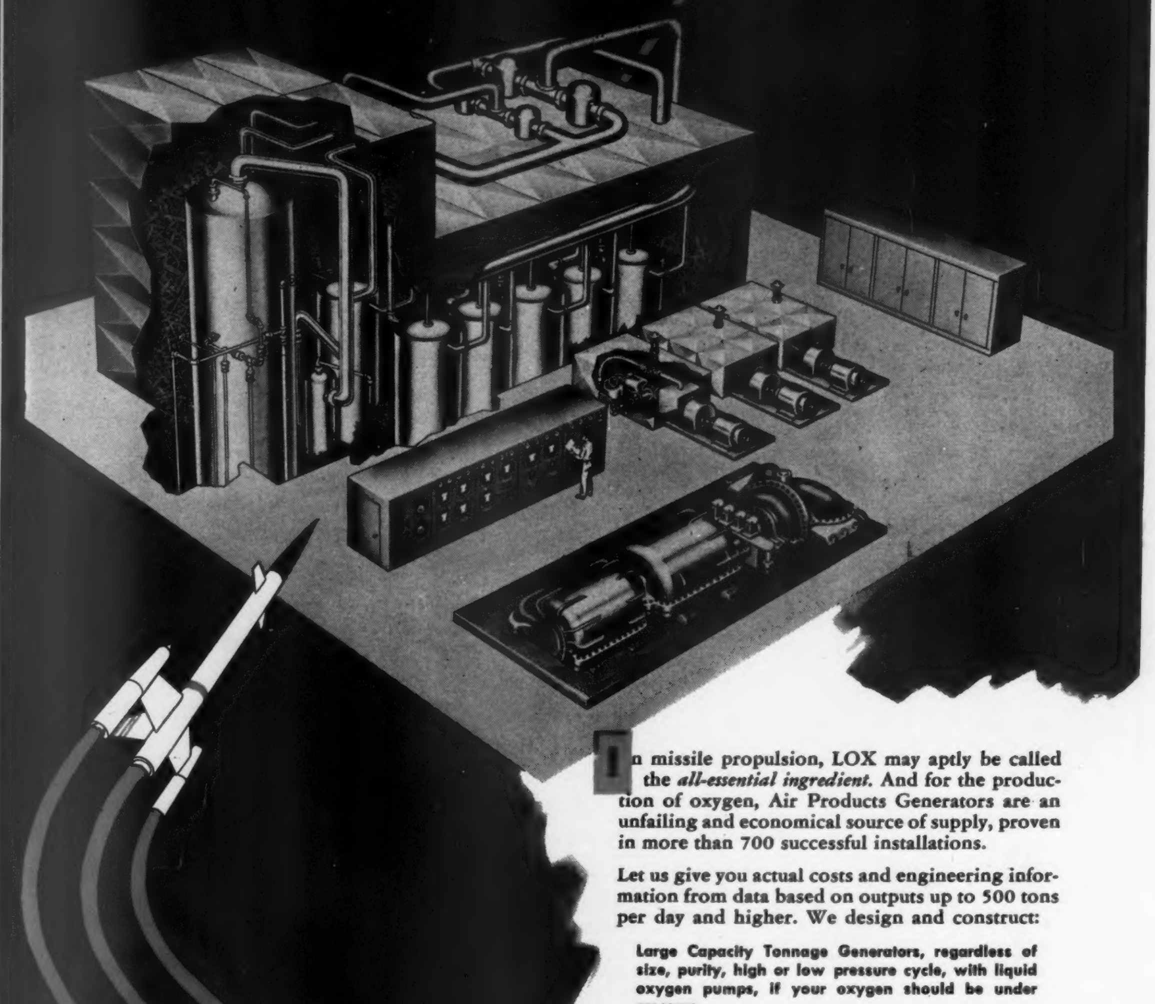

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